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Environmental Support of Naval Aviation

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Forecast Support Branch

STEVEN B. DREKSLER

Computer Sciences Corporation

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A two-pronged approach to providing environmental support to Navy aviation is described. One approach focuses on flight safety and efficiency, and the other focuses on support to the tactical mission planner. Products are discussed in terms of requirements and the technical issues associated with the development or implementation of the products. This insight should be useful not only to the operational, tactical, and environmental communities, but to the R&D community as well.

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ENVIRONMENTAL SUPPORT OF NAVAL AVIATION

1. INTRODUCTION

The environmental community within the Navy has a long history of support to Naval aviation. The primary emphasis of this support has been, and will undoubtedly continue to be, flight safety. In addition to flight safety issues, the advent of "smart weapons" technology, and their sensitivity to environmental effects, has placed increasing demand on the environmentalist for tactical environmental support. Thus, the concept of environmental support of naval aviation has broadened because of a number of significant changes. These changes can be attributed to the following: (1) advances in computer technology (ashore and afloat); (2) development of tactical scale atmospheric models and environmental effects models; (3) development of tactical environmental applications that impact the aviation community; (4) advances in visualization (i.e., techniques and technology to better display environmental information and weapon system performance); and (5) advances in simulation techniques and technology to enhance training, mission planning and mission rehearsal. The compilation presented in this report will attempt to discuss the support to the naval aviation community in light of the above changing technologies.

For simplicity a two-pronged approach to environmental support of naval aviation will be discussed. The approaches will differ primarily because of customer needs. The primary users of the Environmental Product Suite will be the Naval Meteorology and Oceanography Command Detachments (NMOCDs) providing aviation weather forecast support and the meteorology and oceanography (METOC) community on major combatants that provide this support afloat. The primary user for the Tactical Environmental Product Suite will be the tactical mission planners or environmentalists providing this support. Figure 1 shows this two-pronged approach. The starting point for aviation forecast support is the environmental data base that produces state-of-the-atmosphere variables with current atmospheric analyses and forecast models. The next step is to produce aviation impact variables. This is perhaps the most technically challenging segment for aviation forecast support because many of these variables are not typically forecast or verified in numerical weather prediction. The aviation impact variables form the basis for the environmental product suite which is heavily based on customer needs. Examples, as depicted in Figure 1, include Horizontal Weather Depiction (HWD) displays, Optimum Path Aircraft Routing System (OPARS) displays or flight weather briefs prepared in accordance with standard NAVMETOCEANCOM instructions (e.g., COMNAVOCEANCOM, 1989).

The lower pathway depicted in Figure 1 focuses on the tactical mission planners. The starting point is the tactical data base in combination with tactical impact variables such as the atmospheric parameters of the Electro-Optical Tactical Decision Aids (EOTDAs). With the

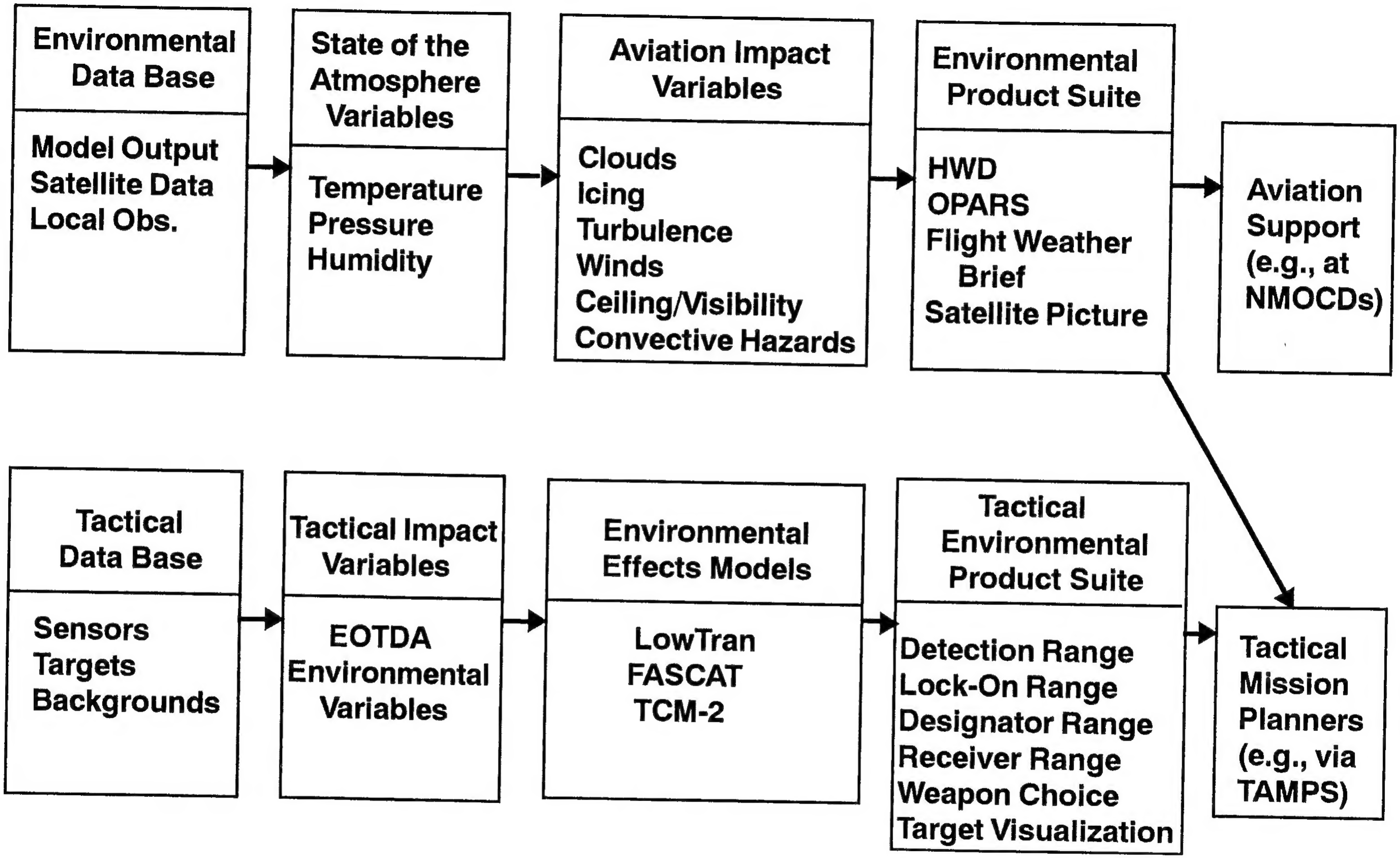

Figure 1. Naval environmental aviation support: environmental product suite (top) and tactical environmental product suite (bottom).

incorporation of environmental effects models, a tactical environmental product suite can be produced with output depictions that appeal to the tactical mission planners working with such systems as the Tactical Aircraft Mission Planning System (TAMPS). The Tactical Environmental Product Suite differs from the environmental product suite in that it presents environmental impacts on sensor or weapon system performance (e.g., detection or lock-on range, target visualization, etc.).

The tactical mission planners are, of course, interested in not only the tactical environmental effects, but also the aviation impact variables and resulting environmental products, since flight safety is always of importance. Thus, for the tactical mission planners, both the environmental and tactical environmental product suites become important complementary aids to use in the decision-making process. In fact, all the products discussed above could be viewed as tools to assist the ultimate customer, the naval aviator.

The next two sections of this report will discuss the environmental and tactical environmental product suites, respectively. The discussion will include the following: (1) environmental parameter requirements and their associated resolutions, frequencies, accuracies and deficiencies; and (2) the visualization requirements of the environmental and tactical environmental information to better provide flight safety and tactical efficiency. The presentation of this information will provide a basis for the development and implementation of environmental support of naval aviation. This insight might be useful not only to the operational tactical and environmental communities, but to the R&D community as well.

The reader should keep in mind that while many of the products shown in this report are presently available in some form, ranging from operational to R&D, a number of the products are also conceptual and are presented to elicit response from the tactical and environmental communities.

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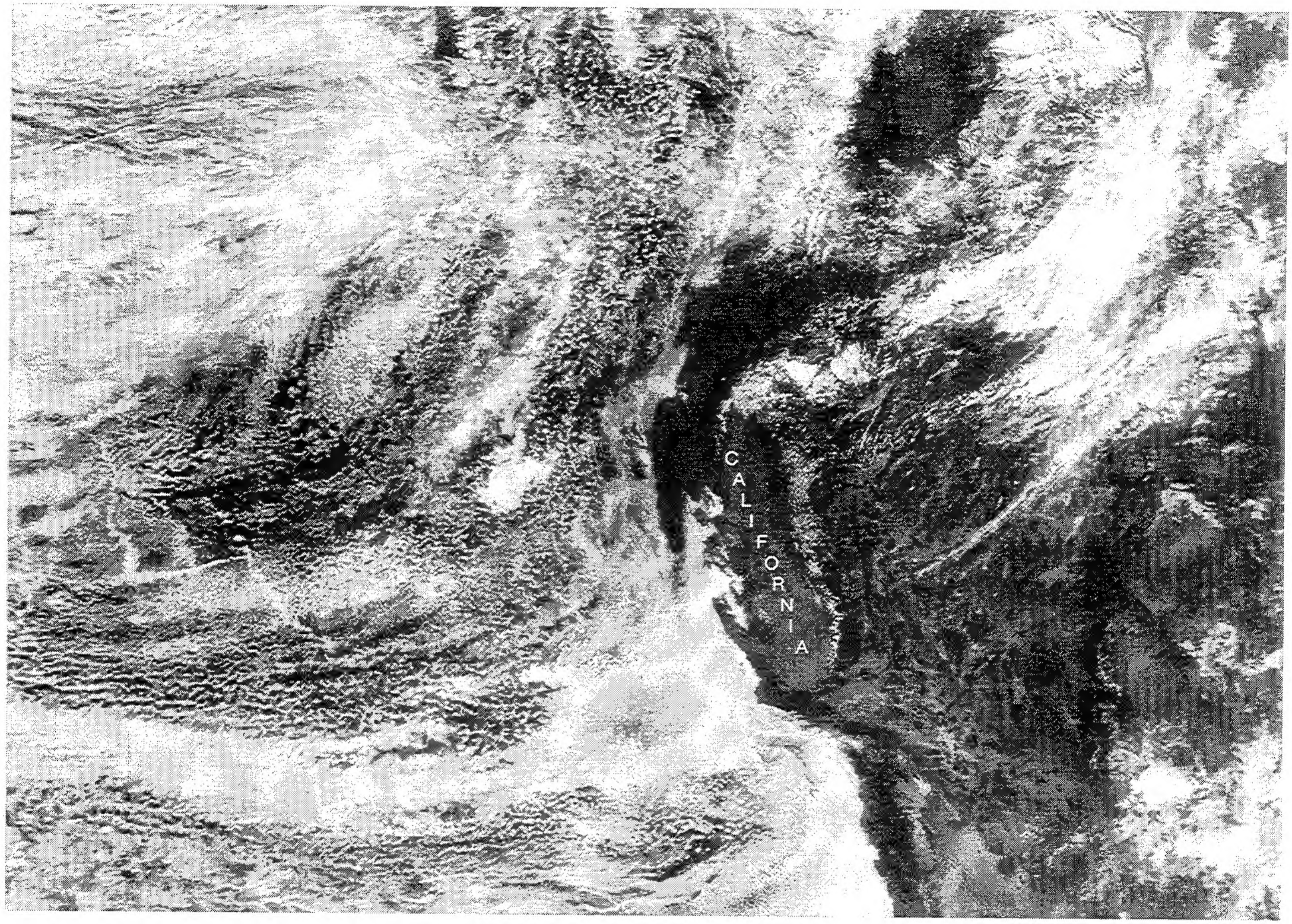
2. ENVIRONMENTAL PRODUCT SUITE FOR NAVAL AVIATION SUPPORT

In aviation weather forecasting there are two time elements for environmental support. The first emphasizes the interpretation of existing weather and short range forecasts. Many operational decisions are made within this category. For example, consider the case of aircraft arriving at a destination or returning to a location and finding that the ceiling and visibility have dropped below landing levels. Many variables drive the decisions that follow, and these decisions have to be made quickly. The second type of forecast is related to planning and will require longer range forecast information. Decisions associated with this category could be fuel and load limits, routing, alternate airport selection, alternate targeting, etc.

As with all environmental support, the further into the future, the less accurate the forecasts. Experienced aviators understand this reduced lack of confidence as the forecast time is increased.

The products presented in this section will emphasize flight safety and efficiency. For each product there are discussions concerning the requirements for the product and the technical issues associated with it.

2.1 SATELLITE PICTURE



A satellite picture is a view of the cloud cover over a geographic scene at a point in time. Animation or looping can show the changing cloud scene. Infrared pictures allow 24-hour display capability.

Requirements

The Tactical Aircraft Mission Planning System (TAMPS) environmental requirements place the satellite photograph as a very high priority product (PEO for Tactical Aircraft Programs, 1993). The satellite photographs can be used for the determination of target and enroute weather as well as for providing battle damage assessment potential. With or without numerical atmospheric model output, the satellite photographs are an essential element for the development of Horizontal Weather Depictions (HWDs). These HWDs are also required as part of the Navy's flight forecast folder for ashore and afloat aviators (NAVOCEANCOMINST 3140.14C, 1989).

Technical Issues

Individual photographs and animated loops present an excellent environmental indicator of past to present cloud conditions, but forecast cloud conditions are dependent on numerical model output. Over-water forecasting of satellite cloud images using a numerical approach has shown some skill out to 36 hours (Nagle, 1992), while over-land skill probably extends to only 3-4 hours. Cloud classifiers have been developed and provide some skill in automatically identifying different types of clouds (Crosiar, 1993). Expert systems are slowly evolving to automatically interpret satellite imagery (Peak and Tag, 1992). This could be extremely important because a skilled meteorologist may not be present to interpret the environmental or tactically relevant information. Direct information from satellite photographs of cloud base and ceiling information is still a technical challenge without model output or in-situ observations. Cloud movement via animation is feasible ashore because of land-based data linkages, but the afloat TESS(3)/SMQ-11/NITES* environment does not as yet have synchronous satellite direct readout capability; future upgrades should remedy this. The portrayal of time evolution of cloud systems not only enables significant weather events to be identified and tracked, but also enables an observer to gain a dynamical understanding of what is happening on the mesoscale (Browning and Szejwach, 1994). Severe weather often exhibits characteristic small scale structure whose rapid development or dissipation can be identified from frequent imagery, especially when sequenced and looped. The high resolution imagery from the Defense Meteorological Satellite Program (DMSP) and the National Oceanic and Atmospheric Administration (NOAA) TIROS satellites, as well as the low resolution imagery from GOES WEFAX, will pass from the SMQ-11 satellite receiver aboard ship to TESS(3), where it will be displayed on a work station for enhancement, annotation, HRD development, etc. (Willis and Markley, 1994). TESS(3) will capture the displayed image and output it to the TESS remote workstation and ultimately on to TAMPS.

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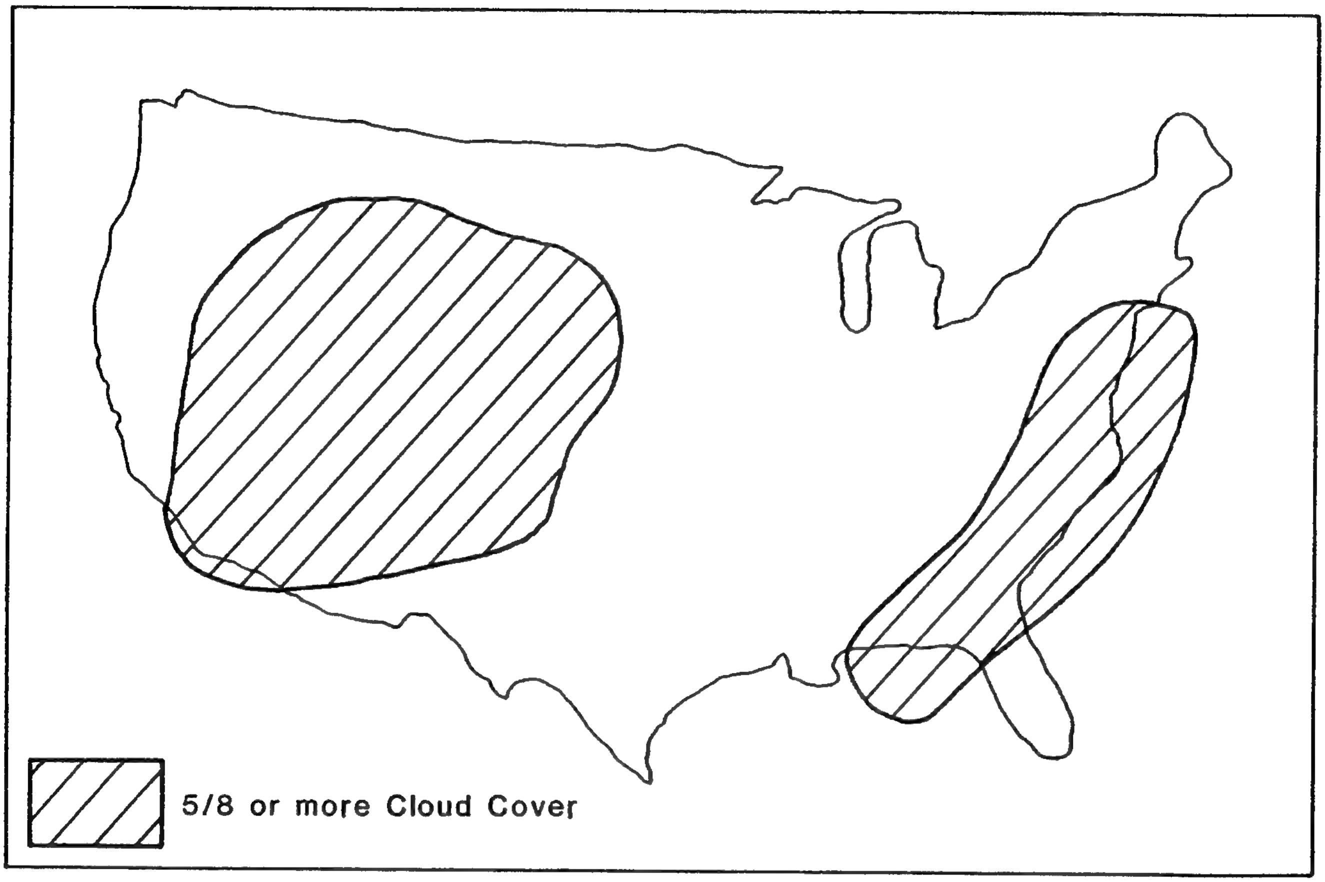
* The Tactical Environmental Support System is a computer workstation that provides environmental information for Navy environmentalists and decision makers. The SMQ-11 is a satellite data receiving system that is linked directly with TESS (3) to provide digital data and imagery for viewing and manipulation. The Navy Integrated Tactical Environmental Subsystem will provide improved meteorological and oceanographic (METOC) data and products to ships and shore activities and be integrated with the Joint Marine Communication and Information System. NITES will permit tactical users access to METOC products.

2.2 CLOUD DEPICTION



The Cloud Depiction shown here is a display of 5/8 or greater cloud cover, which is the cloud amount necessary for Horizontal Weather Depictions. Depictions such as this could be derived from satellite data and/or model output.

Requirements

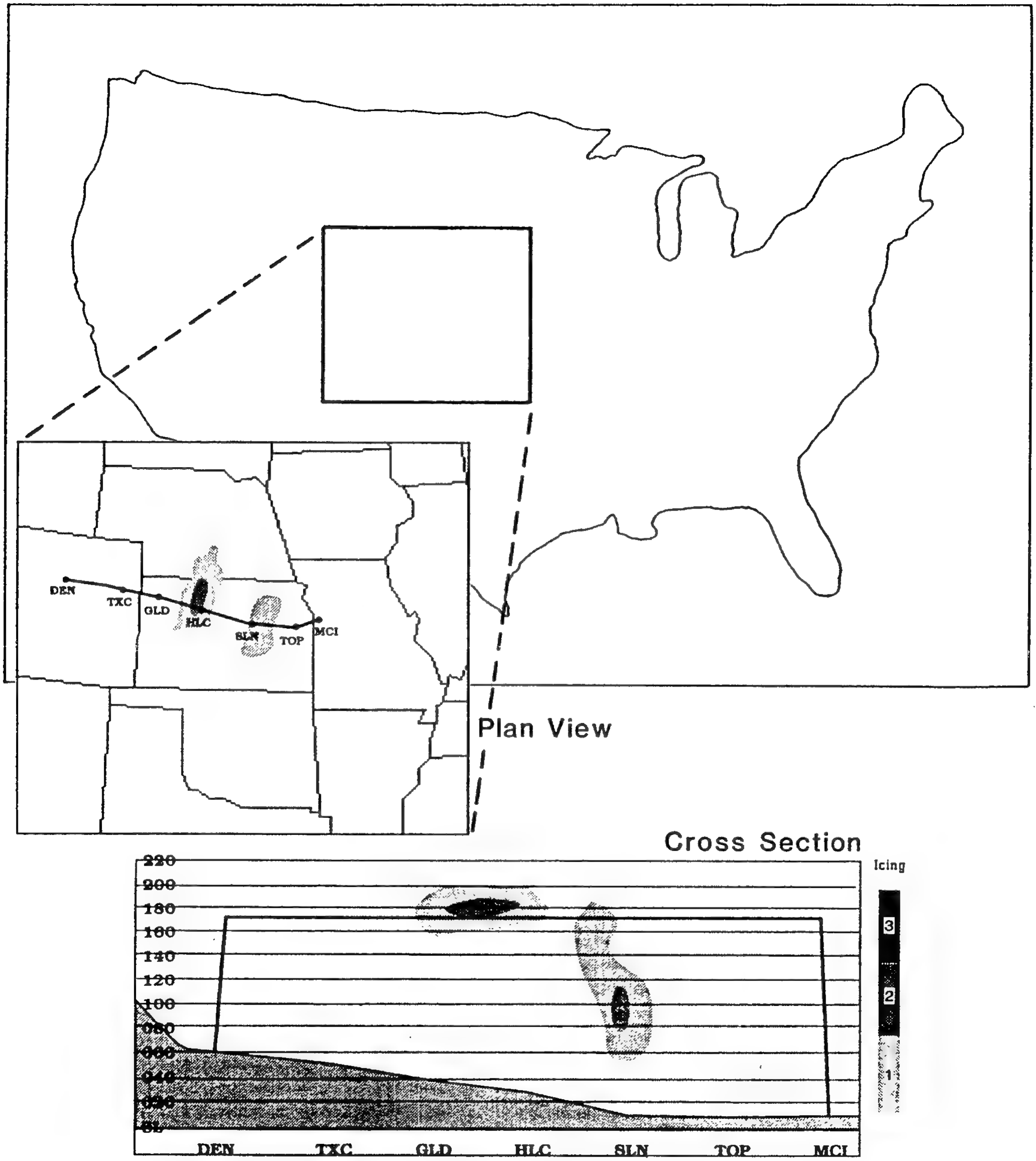
Cloud depictions would be a useful tool in developing HWDs as required by NAVOCEANCOMINST 3140.14C for the flight weather briefing package. In addition, the TAMPS has delineated a requirement for cloud coverage for low, middle, high and total cloud for the flight route out to 96 hours. TAMPS accuracy requirements are 10% for cloud coverage and 100 feet for cloud tops and bottoms (Director, Cruise Missile Project, 1990). TAMPS temporal requirements for cloud depictions range from hourly data (PEO for Tactical Aircraft Programs, 1992) to 6-hourly data (Director, Cruise Missile Project, 1990; PEO for Tactical Aircraft Programs, 1993).

Technical Issues

While the satellite photographs provide a good initial starting point to HWD development, the numerical forecast models* have additional value due to their forecast capability. Model forecast accuracies for cloud cover have not been evaluated for these models. Empirical adjustments might be necessary to delineate tops/bottoms of cloud decks. A smoother might be necessary for visually appealing horizontal depictions of cloud model output. HWDs are currently hand-drawn or interactively generated by the environmental operator. The cloud depiction product could be an important element to the HWD. Another source of data that is just starting to be explored by the Navy research and operational communities is the Air Force Real-Time Nephanalysis (RTNEPH) (Hamill et al., 1992). The RTNEPH is a cloud analysis model generated by Air Force Global Weather Central with most of its data coming from DMSP satellites supplemented by conventional observations.

* The Navy has developed both global and regional forecast models. The Navy Operational Global Atmospheric Prediction System (NOGAPS) (Rosmond, 1992) is the large-scale global model that provides weather forecast guidance for up to 5 days. NORAPS (Navy Operational Regional Atmospheric Prediction System; Hodur, 1982; Burk and Thompson, 1989), is currently used to provide regional or mesoscale weather forecast guidance for up to 48 hours. A new higher resolution model, the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) (Hodur, 1993) is currently being developed and tested.

AIRCRAFT ICING HAZARD



Aircraft Icing Hazard would depict plan and cross-sectional views by general measures of icing potential or as a function of type of aircraft. Elevation values shown here are in hundreds of feet.

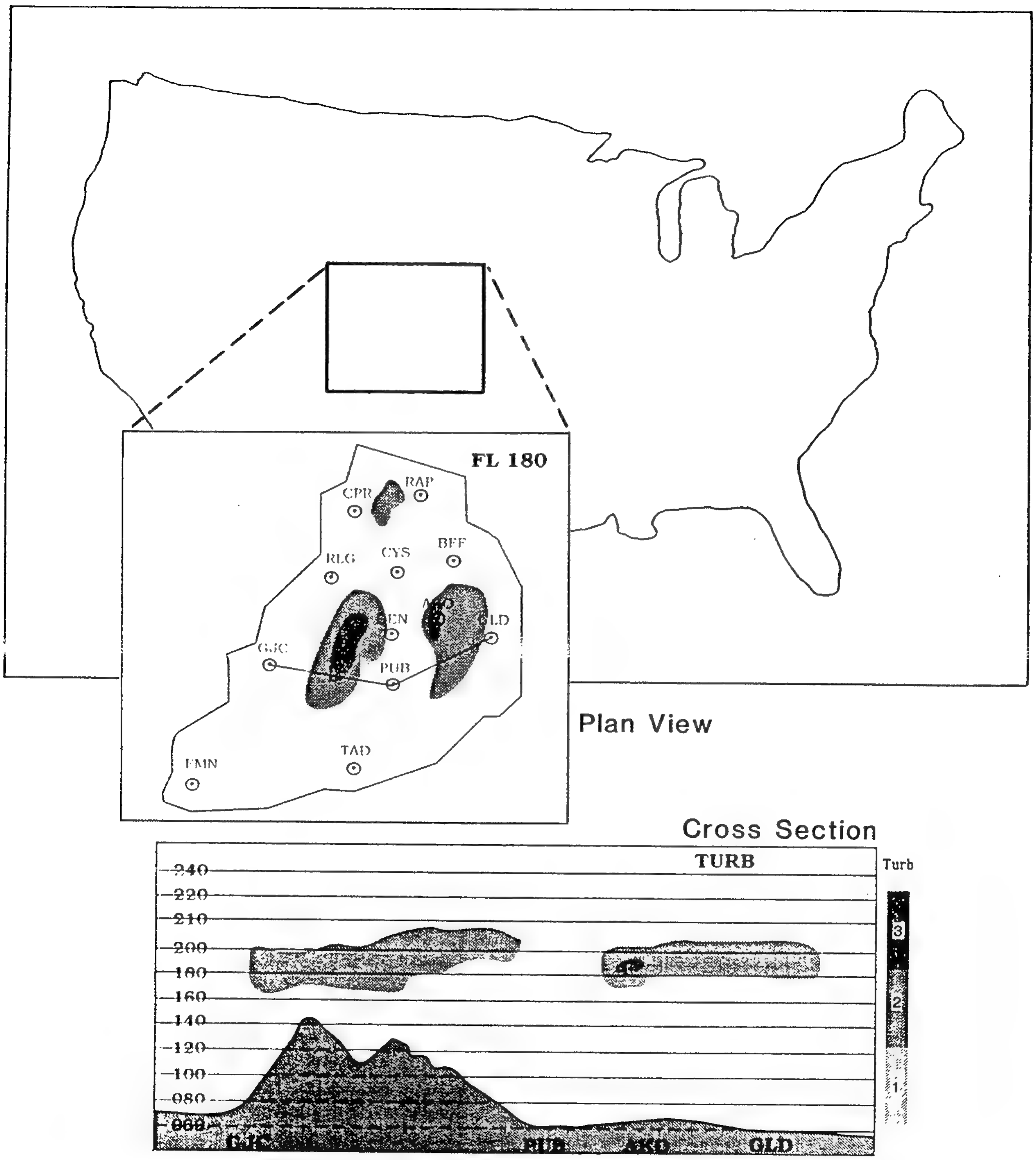
Requirements

TAMPS requires Aircraft Icing Hazard displays to be part of the HWD. Horizontal resolution of data has been requested at 10 nautical mile intervals with vertical information every 1000 feet. Temperal requirements range from hourly to 6-hourly data extending out in the forecast period as far as 96 hours. Icing information is also required as part of the enroute-data segment of the flight weather briefing form DD-175-1 (NAVOCEANCOMINST 3140.14C).

Technical Issues

The most important factors in the production of aircraft icing are supercooled liquid water content, temperature, and droplet size, as well as the specific aircraft (airframe and engine components). Because model output environmental parameters need to be converted to the Aviation Impact Variable-Aircraft Icing, technically sound algorithms are required together with very high resolution (in time and space) atmospheric model output. While algorithms do exist and products are produced, very little verification has been done with current models (Vogel, 1988; Siquig, 1993). The National Weather Service has found that warning areas for icing cover such large areas that they tend to be only marginally useful; they lack specificity and preciseness in their forecasts (Sankey, 1994). The Forecast Systems Laboratory's Aviation Division (part of NOAA's Environmental Research Laboratory) is just starting to examine the accuracy of icing forecasts as derived from numerical model output (Cairns and Miller, 1993). Model output accuracy for icing has not been evaluated for Navy model output. On-scene high-resolution data collection, assimilation, and analysis, as well as forecasting, should be explored. New techniques are currently being developed to combine model output with satellite data to produce an aircraft icing watch product (Lee et al., 1994). The satellite data is from the Special Sensor Microwave Imager (SSM/I) and the infrared sensors of the Defense Meteorological Satellite Program polar orbiting satellites. The inclusion of satellite data shrinks the aircraft icing warning areas considerably with respect to products based solely on model output. Interactive aircraft icing display technology is being developed by the Research Applications Program of the National Center for Atmospheric Research (Carmichael, 1994).

2.4 AIRCRAFT TURBULENCE HAZARD



Aircraft Turbulence Hazard would depict plan and cross-sectional views by measures of light, moderate and severe turbulence. Elevation values shown are in hundreds of feet.

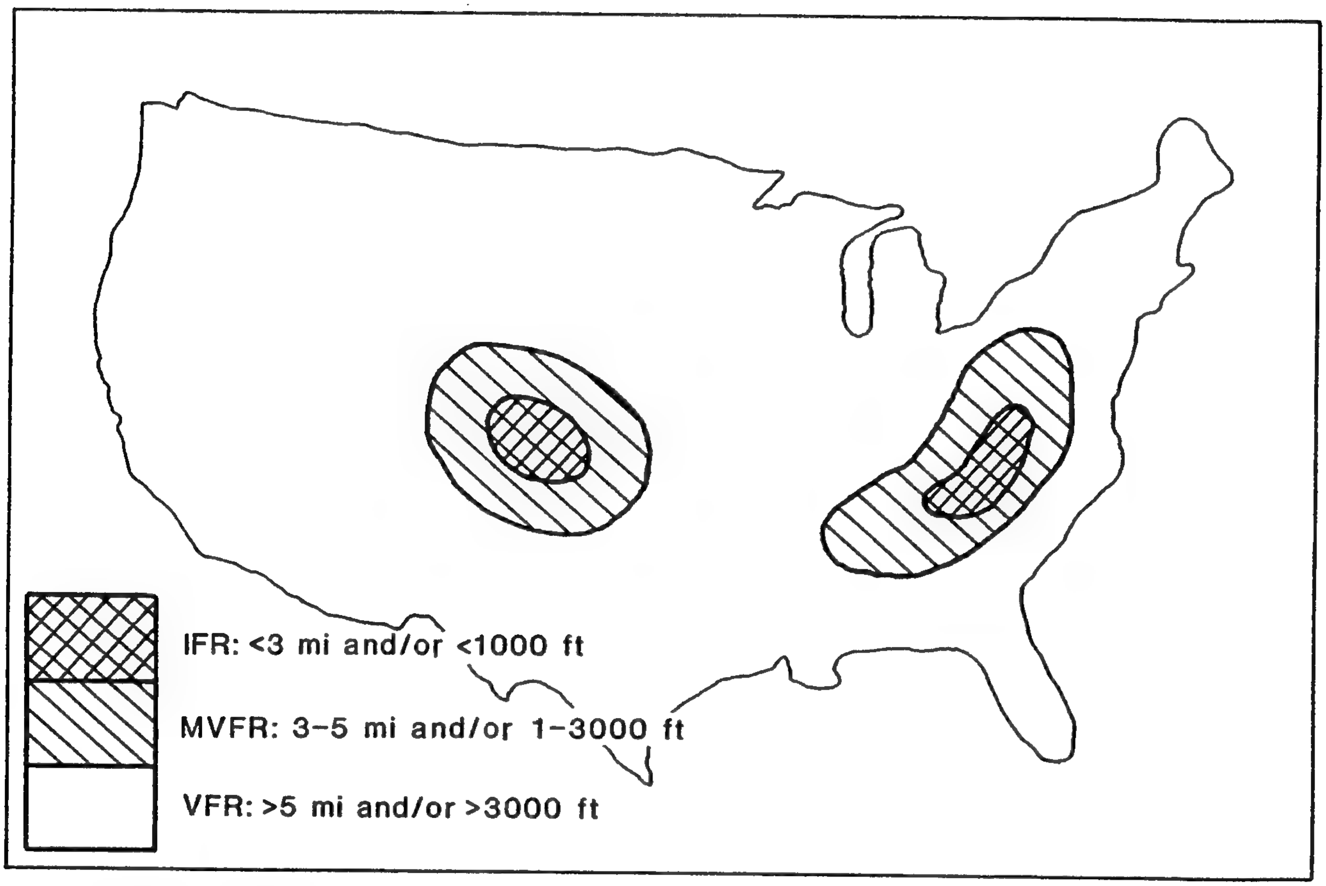
Requirements

TAMPS requires Aircraft Turbulence Hazard displays to be part of the HWD. Horizontal resolution data requests have ranged from 10 nautical miles to 60 nautical miles with vertical information requested at 1000 feet intervals. Accuracy demands for the regions of turbulence have been documented at 100 feet. Temperal requirements range from hourly to 6-hourly data extending out in the forecast period as far as 96 hours. Turbulence information is also required as part of the enroute-data segment of the flight weather briefing form DD-175-1 (NAVOCEANCOMINST 3140.14C).

Technical Issues

Aircraft turbulence appears in many different forms: clear air, thunderstorm, mountain wave, wind shear, jet stream and gust front. Because model output environmental parameters need to be converted to the Aviation Impact Variable-Aircraft Turbulence, technically sound algorithms are required together with very high resolution (in time and space) atmospheric model output. While algorithms do exist and products are produced, very little verification has been done. The National Weather Service has found that warning areas for turbulence cover such large areas that they tend to be only marginally useful; they lack specificity and preciseness in their forecasts (Sankey, 1994). The Forecast Systems Laboratory's Aviation Division (part of NOAA's Environmental Research Laboratory) is just starting to examine the accuracy of turbulence forecasts as derived from numerical model output (Cairns and Miller, 1993). Model output accuracy for turbulence has not been evaluated for Navy model output. On-scene high resolution data collection, assimilation, and analysis, as well as forecasting, should be explored. Interactive display technology for aircraft turbulence is being developed by the Research Applications Program of the National Center for Atmospheric Research (Carmichael, 1994).

2.5 VISIBILITY/CEILING WEATHER RESTRICTIONS



Visibility/Ceiling Weather Restrictions would depict whether a flight would be under instrument, marginal or visual flight rules.

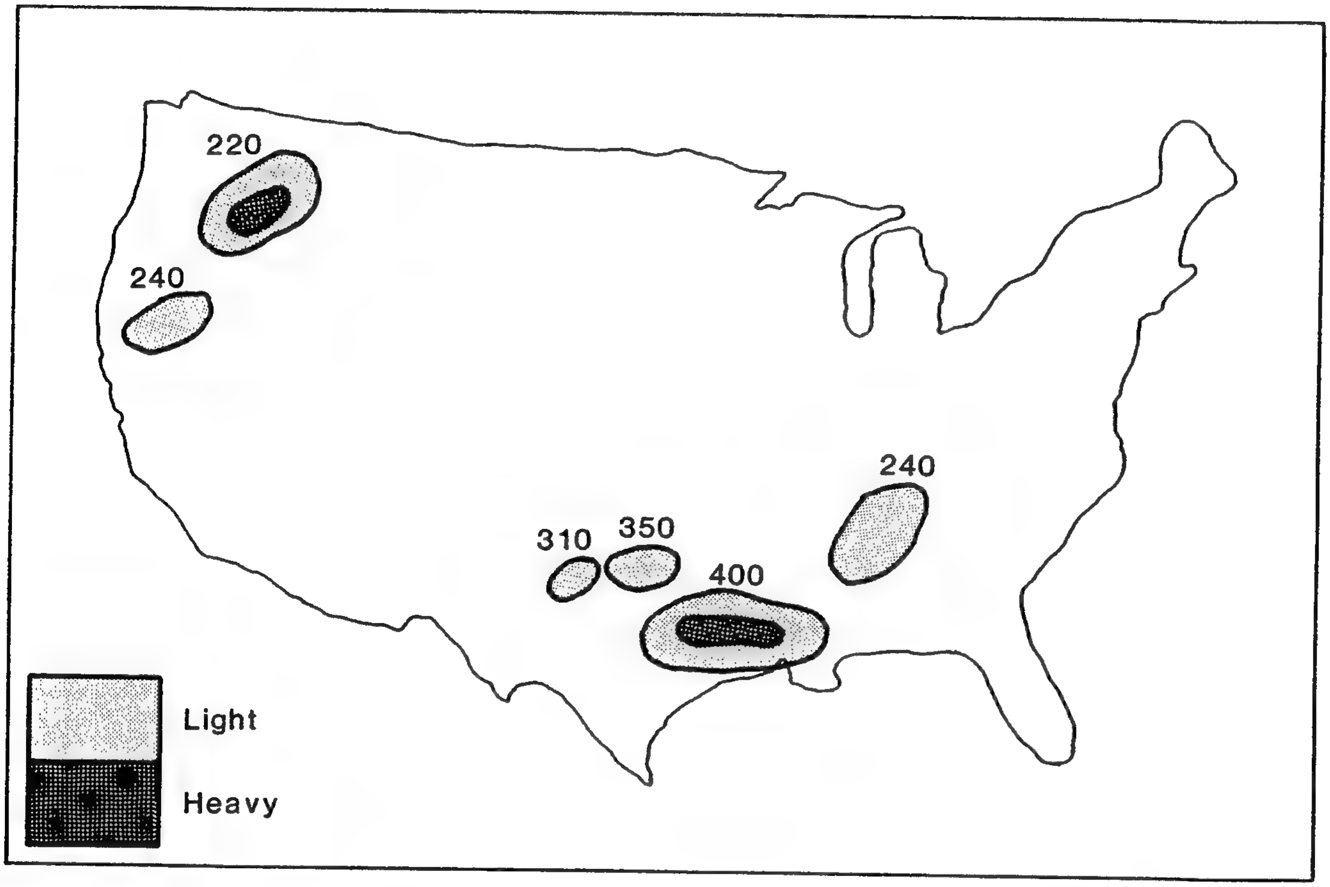
Requirements

TAMPS requirements exist for visibility and cloud base. Horizontal resolution data requests have ranged from 10 nautical miles to 60 nautical miles with vertical information requested at 1000 feet intervals. Temporal requirements range from hourly to 6-hourly data extending out to 96 hours. Accuracy demands have been documented at 1 nautical mile for horizontal and slant range visibility. Cloud base accuracies have been requested at 100 feet. Visibility/Ceiling information are an important element of the flight weather brief and the preparation of DD Form 175-1 (NAVOCEANCOMINST 3140.14C). Visibility/Ceiling Weather Restrictions play an important role in flight safety ashore and afloat and for determining whether a flight will be under instrument or visual flight rules (IFR or VFR).

Technical Issues

A Visibility/Ceiling Weather Restrictions product is currently produced and distributed by the National Weather Service. No equivalent product currently exists in the Navy, but model output and algorithms currently exist to produce this kind of product either in man-machine or automated mode. If a Navy product was developed, it would have to be evaluated for skill and for determination of its value to the aviation community. The Forecast Systems Laboratory (Environmental Research Laboratory/NOAA) has developed a methodology to evaluate visibility and ceiling model output (Cairns et al., 1993) and is currently evaluating model output of several analysis and forecast models.

2.6 RADAR SUMMARY DEPICTION



The Radar Summary Depiction shown here is a compilation of numerous radar returns located throughout the country. Depicted are light and heavy returns with tops in 100's of feet. Areas of interest could be regionalized and animation could display "past to present" history.

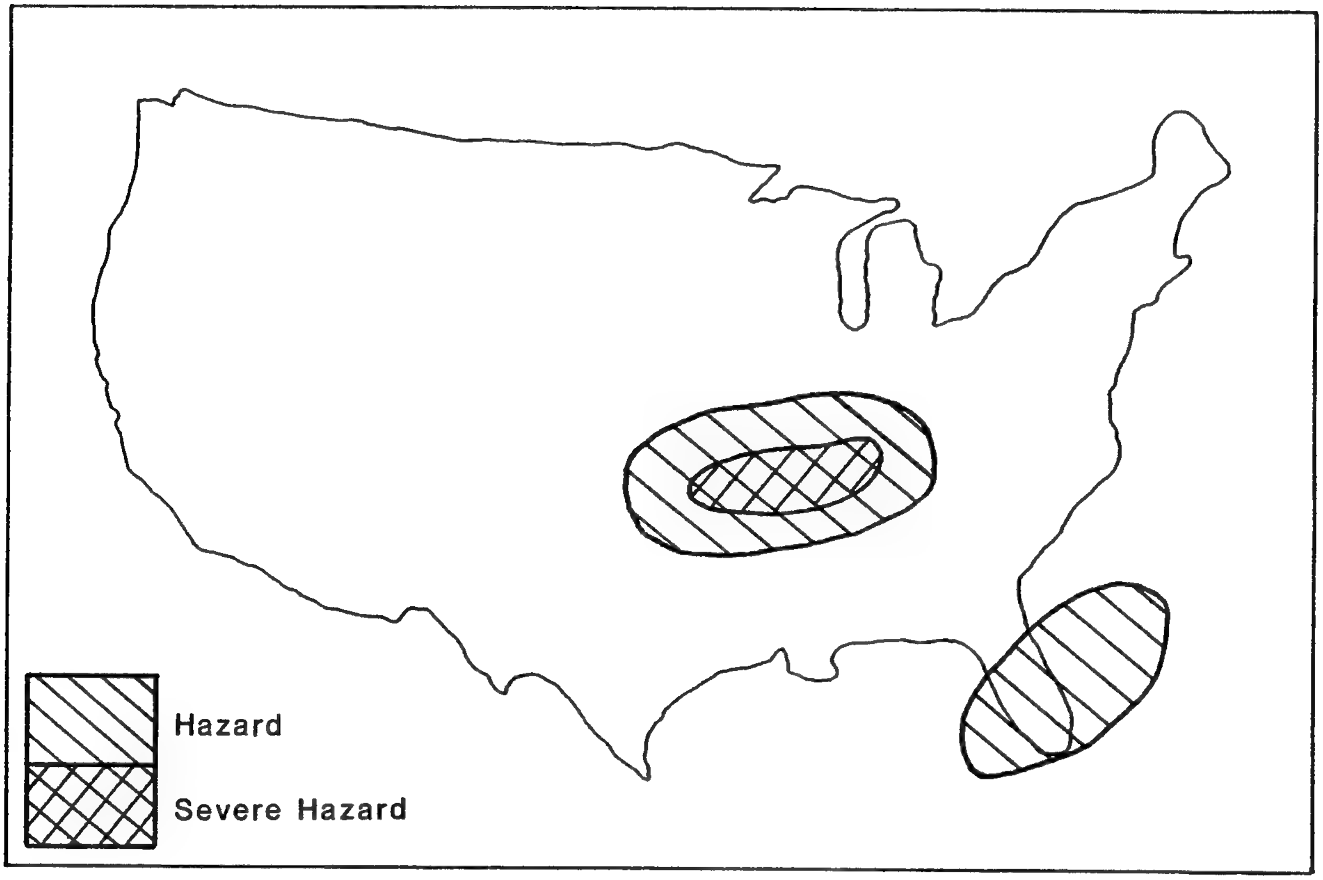
Requirements

The location of precipitation is a requirement for the flight weather briefing package (NAVOCEANCOMINST 3140.14C). TAMPS environmental requirements indicate the need for precipitation information. The Radar Summary Depiction is a "quick look" at the present radar returns and in still or in animated form provides insight with respect to frontal activity, turbulence and thunderstorm potential for takeoff, landing and enroute weather.

Technical Issues

In areas of the globe where there are extensive radar networks, radar data are compiled and forwarded to users as a radar summary, which is a very "quick look" at the present radar return situation. The National Weather Service and numerous private agencies distribute this kind of data for the continental U.S. region. The Navy could tap into these sources and distribute similar displays. Outside data-rich radar regions, summaries such as this are not available (refer to Precipitation Depiction, section 2.8). Animation or looping sequences of radar data are very useful tools if storage capacity exists. Short term forecasts or extrapolation of the radar loops has been explored, but because of the occurrence of dynamical changes, the results would not be reliable after a few hours. With the new NEXRAD doppler radar network being implemented, further potential exists for characterizing severe weather that impacts aviation decision-making.

2.7 AIRCRAFT THUNDERSTORM/LIGHTNING HAZARD



The Aircraft Thunderstorm/Lightning Hazard display would indicate convective hazard regions with strong thunderstorm/lightning potential. Lightning network data could also be overlaid.

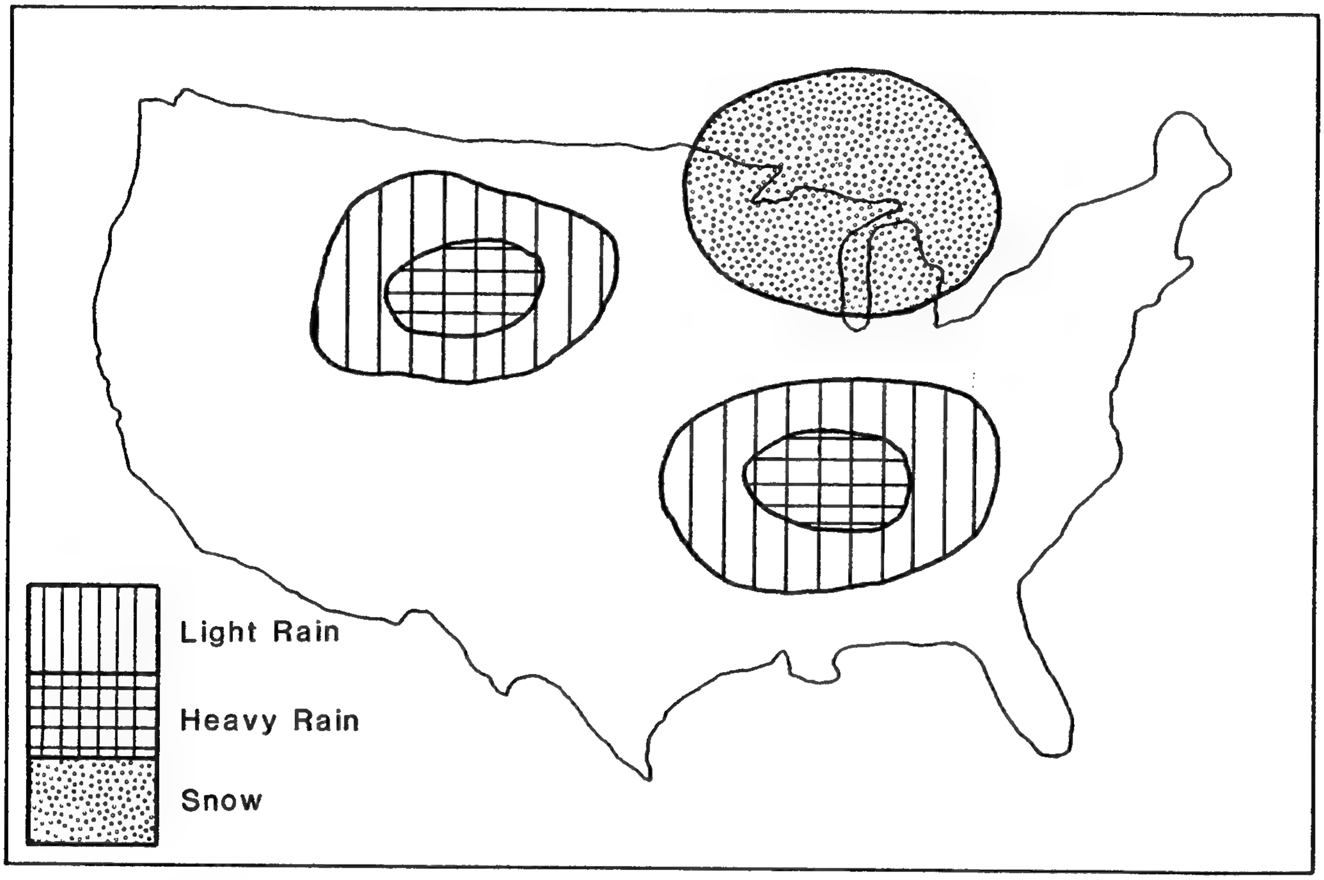
Requirements

TAMPS has documented the requirement for display of hazardous conditions for flight routes. Horizontal and vertical scale requirements for data are 10 nautical miles and 1000 feet, respectively. Temporal requirements range from hourly to 6 hourly, out to 96 hours. Hazardous conditions such as thunderstorms are an integral part of the Navy's flight forecast folder (NAVOCEANCOMINST 3140.14C).

Technical Issues

Thunderstorms are one of the most formidable weather hazards to naval aviation. They are associated with turbulence, moderate to severe updrafts and downdrafts, hail, icing, lightning, precipitation, gust fronts and tornadoes. Short term indications are readily available from radar returns and observational data; long term forecasting at a broad scale could be derived from numerical model output. For example, the convective available potential energy field should be a strong indicator of thunderstorm/lightning hazard for larger scale model output. Higher resolution models could use stability indices (e.g., Showalter) to depict thunderstorm regions, but this approach would have to be evaluated prior to operational implementation. Lightning networks currently in existence could provide a "quick look" of current lightning activity; this could also be displayed on this type of hazard product.

2.8 PRECIPITATION DEPICTION



The Precipitation Depiction would indicate regions of light or heavy rain and/or snow. Displays could reflect short-term rain rates or longer-term precipitation.

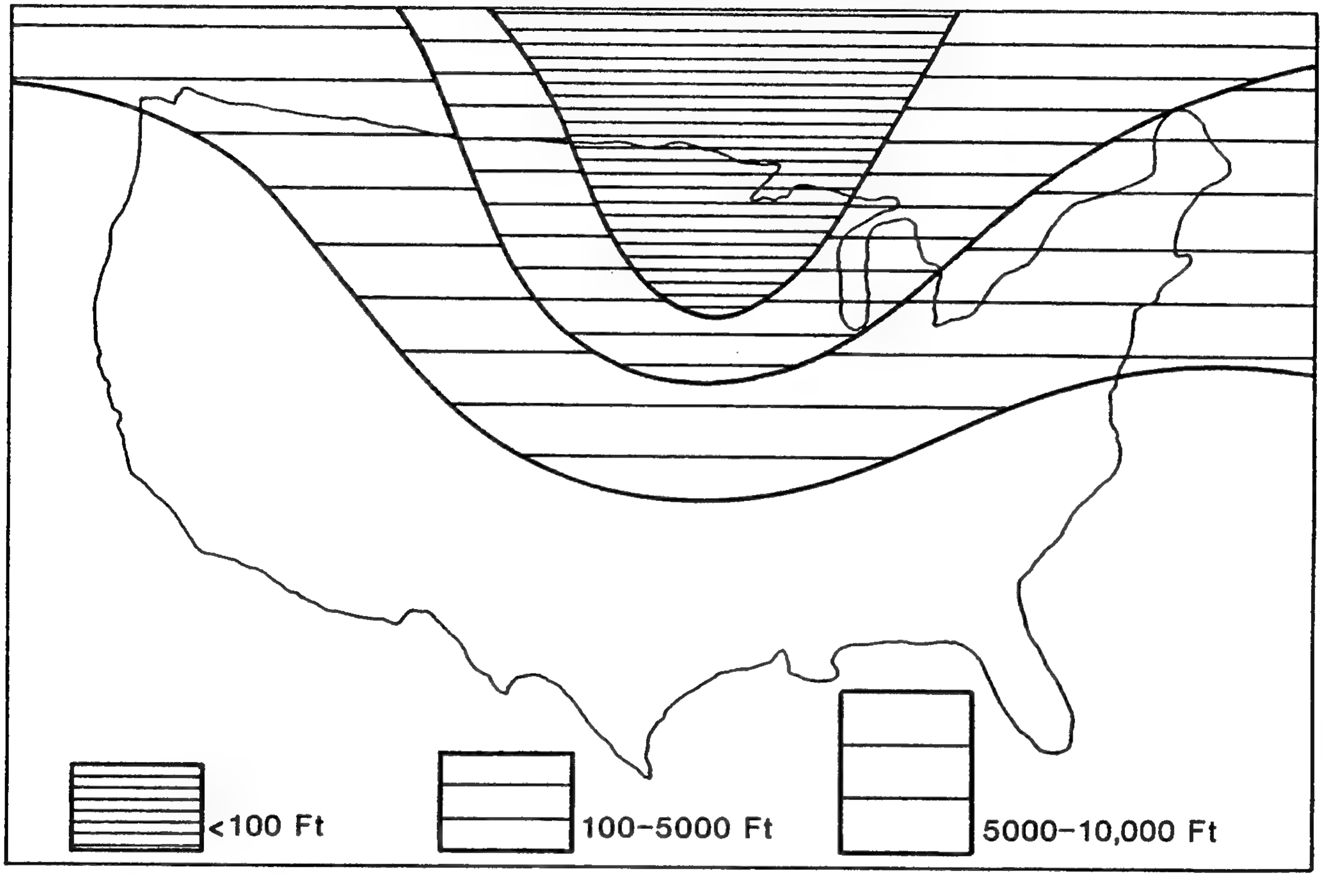
Requirements

TAMPS has documented the requirement for rain rate information. Data have been requested for grid field horizontal resolutions ranging from 10-60 nautical miles. TAMPS temporal requirements for precipitation range from hourly data to 6-hourly data with forecasts extending out to 96 hours. Precipitation is an important element on the enroute-data and terminal forecast sections of DD Form 175-1 of the flight weather briefing package (NAVOCEANCOMINST 3140.14C).

Technical Issues

Precipitation can be deduced from numerical model output. Within the last few years, there has been significant interest in the National Weather Service to evaluate the numerical model skill to predict precipitation (Cairns et al., 1993). The Navy does not as yet have an equivalent effort. Rain rate information can also be deduced for the initial state (nowcasting) by using microwave radiometric data from the special sensor microwave imager (SSM/I) on the DMSP satellites over water, and surfaced-based observations over land. In addition, there are satellite brightness and radar data algorithms that can provide an instantaneous picture of the "present" rain rate. Over land, extrapolation can provide some skill for several hours, but numerical model output provides the best hope for forecasts beyond 6 hours. On-scene high resolution data collection, assimilation and analysis, as well as forecasting, should also be explored.

2.9 FREEZING LEVEL



The Freezing Level Display depicts shaded regions of the freezing level. The criteria for shading can be variable depending on the situation.

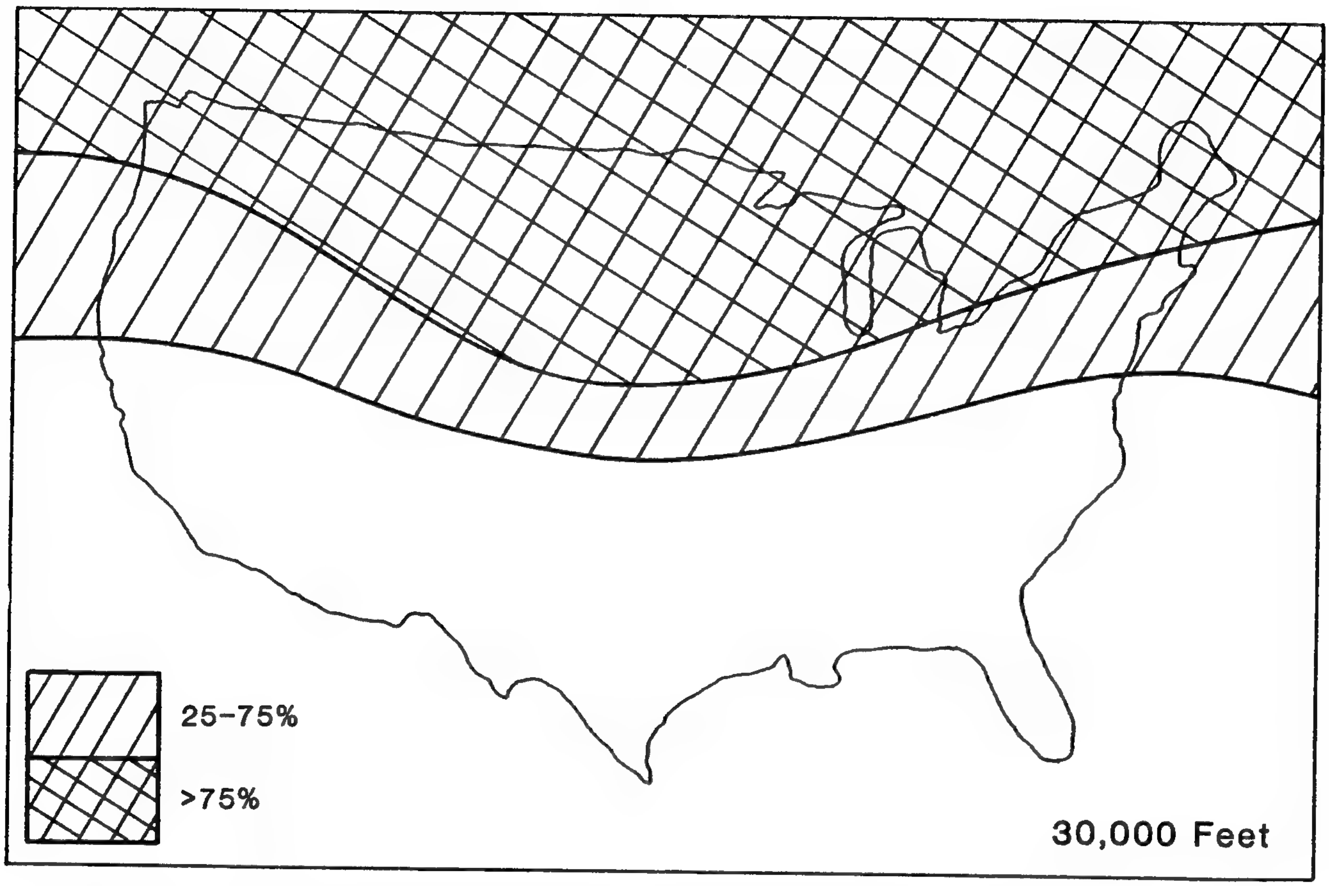
Requirements

TAMPS has a requirement for freezing level grid information. Data have been requested for grid field horizontal resolutions ranging from 10-60 nautical miles and vertical resolutions of 1000 feet. TAMPS temporal requirements for freezing level information range from hourly to 6-hourly data with forecasts needed out to 96 hours. Accuracy demands have been documented at 100 feet. Freezing level information is required as part of the flight forecast folder and DD Form 175-1 (NAVOCEANCOMINST 3140.14C).

Technical Issues

Freezing level information is an important element in aircraft/helicopter icing potential and ashore/afloat takeoff and landing decision-making. In addition, lightning strikes on aircraft are most likely to occur near the freezing level (refer to Section 2.3 on Aircraft Icing Hazard depiction). It also happens to be the temperature at which the most dangerous mixture (too rich) of aviation gas occurs (FNOC, 1986). Freezing levels can be deduced from upper air observations, satellite sounding data, and numerical model output. Numerical modeling should provide reasonable estimates of the freezing level with confidence in the forecasts decreasing out in time. The most challenging technical issues arise with frontal situations where the definition of the freezing level is complex and needs very high resolution information. On-scene high resolution data collection, assimilation and analysis, as well as forecasting, should also be explored.

2.10 CONTRAIL PROBABILITY



The Contrail Probability Depiction displays regions where there is a high probability of contrail formation. Depictions could be displayed at elevation levels or constant pressure surfaces.

Requirements

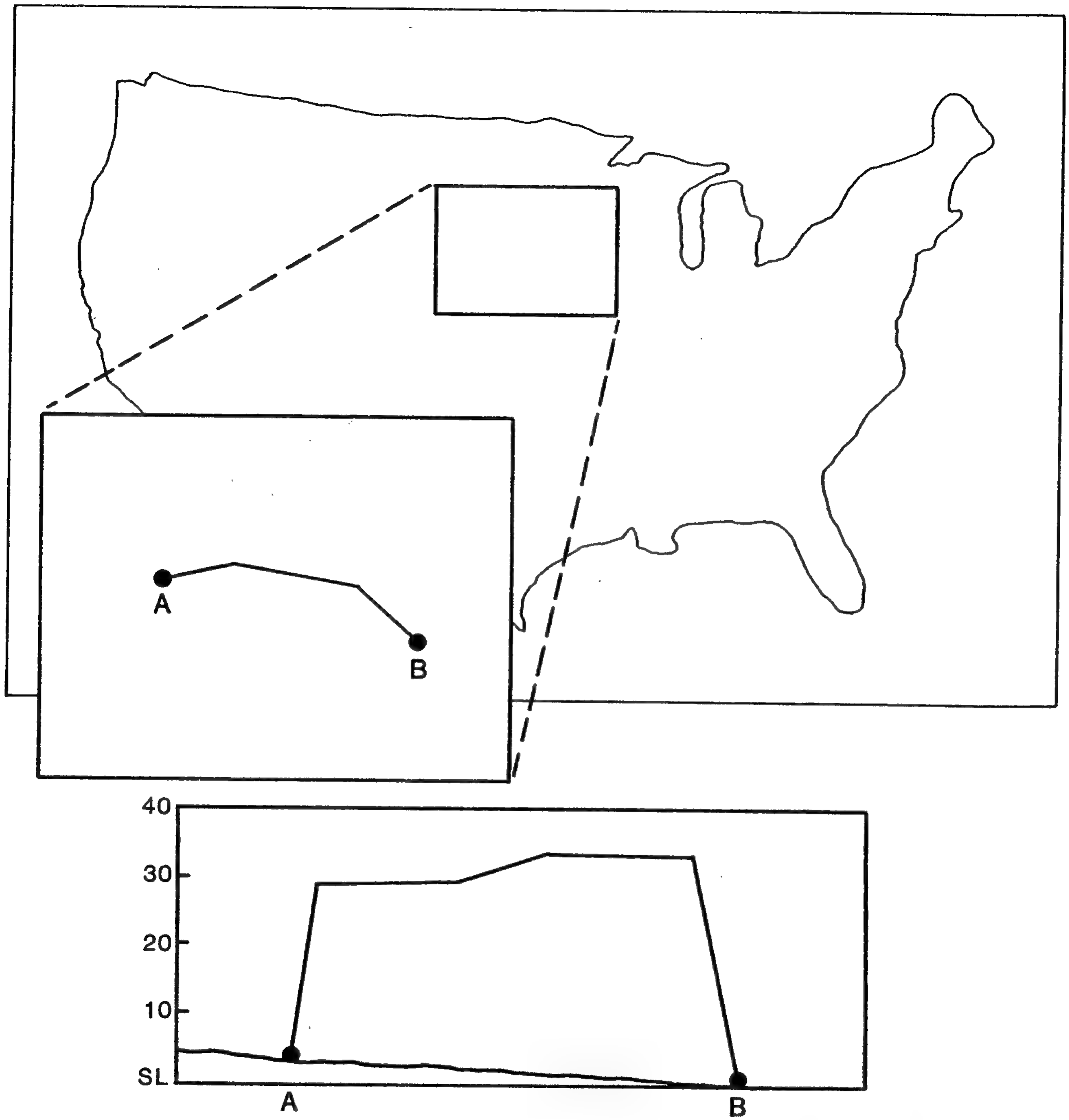
TAMPS requirements exist for contrail level information. Horizontal resolution requirements have been documented at 10 nautical miles with vertical level information ranging from 1000 feet intervals to requests for contrail probability at the 400, 300, 200 and 100 millibar levels. Temporal requests have ranged from hourly to 6-hourly data extending out in forecast time to 96 hours.

Technical Issues

The forecasting of contrails is a military problem since commercial aircraft are comfortable with contrails as a collision avoidance measure. Military aircraft benefit from being hidden. In addition, contrails are an unfavorable weather factor in refueling operations because of reduced visibility in the rendezvous area (FNOC, 1986).

There are two types of contrails. Aerodynamic contrails are caused by pressure reduction that accompanies airflow around aircraft surfaces. Exhaust contrails arise from the addition of moisture to the atmosphere from the aircraft exhaust gases and are usually more dense and persistent than aerodynamic contrails. Both types are a function of temperature and humidity. Since the amount of moisture and heat added by a typical aircraft engine can be determined by design specifications, algorithms can thereafter determine contrail probability as a function of ambient temperature and humidity derived from model output. Forecast results in probabilistic form have been considered good (FNOC, 1986).

2.11 OPTIMUM PATH AIRCRAFT ROUTING



Optimum Path Aircraft Routing provides the opportunity to route from point A to point B while maximizing fuel consumption efficiency. It provides a flight planning service to the naval aviation community and is available from Fleet Numerical Meteorology and Oceanography Center.

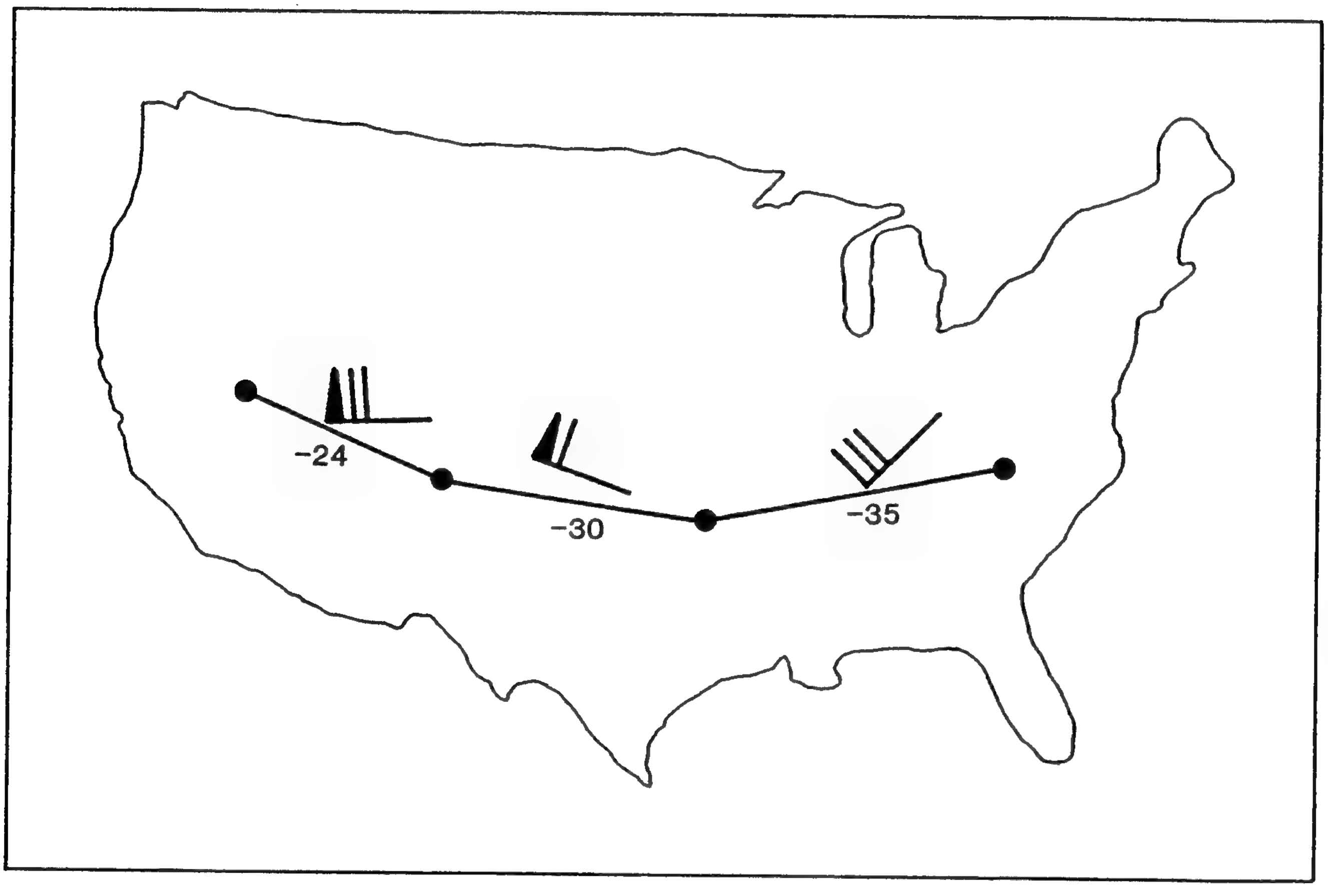
Requirements

Optimum Path Aircraft Routing is a procedure to help support the guidelines outlined in the NATOPS General Flight and Operating Instructions (OPNAVINST 3710.1P, U.S. Navy, 1992b). The Optimum Path Aircraft Routing System is an optional element of the flight forecast folder (NAVOCEANCOMINST 3140.14C).

Technical Issues

The Optimum Path Aircraft Routing System (OPARS) has been developed by Fleet Numerical Meteorology and Oceanography Center as a preflight planning tool. A recommended customized flight plan is provided by using state-of-the-art computers and atmospheric models to analyze the latest environmental forecast data and most fuel efficient flight profile for a specific aircraft (Garthner, 1990). Primary usage is in the 12 to 24 hour time frame. OPARS also has the capability to calculate the following: amount of fuel to load in order to arrive with a specific reserve; maximum cargo/stores for a particular flight; amount of fuel needed to "top off" for inflight refueling; maximum time on station; mandatory over-water reporting positions; and fuel usage for a specific route and/or altitude. The environmental parameters that are relevant are temperature and wind which affect performance and speed. Accuracies have been steadily improving over the years. For example, wind errors have been reduced 20% in the last seven years as numerical models have improved. In the summer there are smaller speed errors than direction errors, with the opposite occurring in winter. Customer satisfaction is high.

2.12 FLIGHT LEVEL WINDS/TEMPERATURE



Flight Level Winds/Temperature Display would reflect average values for flight segments.

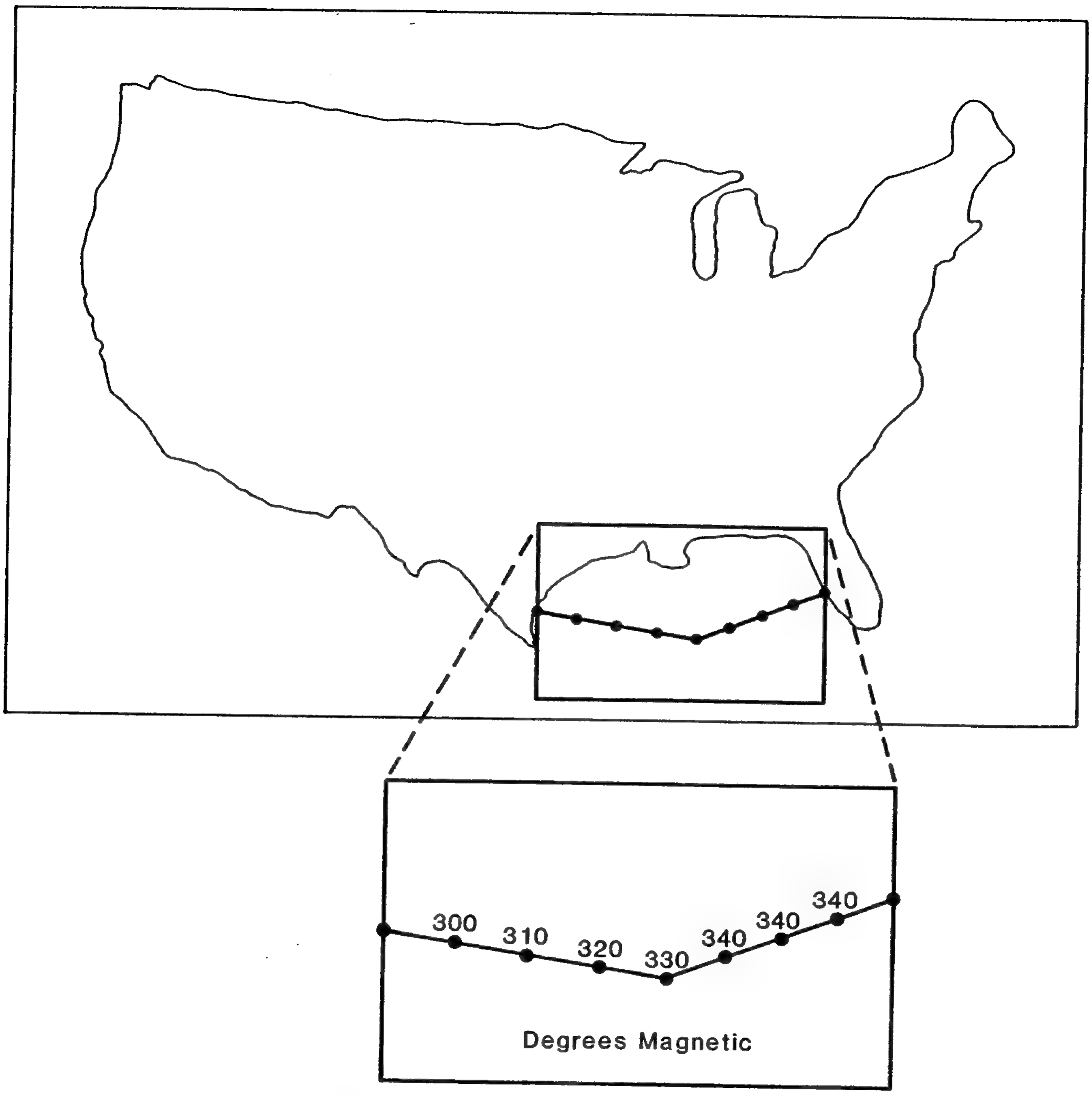
Requirements

TAMPS has environmental requirements for winds and temperatures. Horizontal resolution requirements range from 10 to 60 nautical miles with vertical resolution requirements ranging from 1000 to 5000 feet. Temporal requirements range from hourly to 6 hourly. Accuracy requirements for wind have been documented at 1 knot for speed and 10 degrees for direction; temperature accuracies have been requested to 1 degree centigrade. Flight level winds and temperatures are an important element of the enroute data segment of the flight weather briefing package (NAVOCEANCOMINST 3140.14C).

Technical Issues

Atmospheric model improvements over the past 10 years have greatly improved forecast winds and temperatures. The Navy Operational Global Atmospheric Prediction System (NOGAPS) 12-24 hour wind errors at upper levels in the Northern Hemisphere are approximately 7-12 knots with direction errors between 25-35 degrees. The NOGAPS 12-24 hour temperature errors at upper levels in the Northern Hemisphere are approximately 1 1/2-2 degrees centigrade (Goerss, 1994). Higher resolution atmospheric models with improved physics could probably improve these statistics. These kind of comparative studies need to be done.

2.13 DITCH HEADINGS



Ditch Headings present information to land aircraft more safely in over-water emergencies, into the wind and in the wave trough.

Requirements

TAMPS requirements have been documented for over-water ditch heading information at 60 nautical mile intervals and for a temporal resolution of 6 hours. Accuracy requirements have been requested to the 10% level. Ditch heading information is a requirement for the flight forecast folder for over-water flights (NAVOCEANCOMINST 3140.14C).

Technical Issues

Ditch headings provide information to land aircraft in over-water emergencies more safely. Input data required to provide this information include surface wind speed and direction and wave direction to ensure an up-wind and down-trough landing. Magnetic variation is another input for directional accuracy (NAVOCEANO, 1986). The output is magnetic headings for individual locations or along a route. A third generation wave prediction model called WAM (which stands for Wave Model) has recently been installed at Fleet Numerical Meteorology and Oceanography Center. The WAM has shown better skill than previous wave models (Wave Model Development and Implementation Group, 1988) and should provide the Navy with improved accuracy of wave input to the ditch heading determination. Because there are limited statistics available for accuracy determination for wave direction, little can be said about confidence in output answers. Coupled ocean-atmosphere models provide the ability to further improve wave directional model output. Research is currently underway toward that end.

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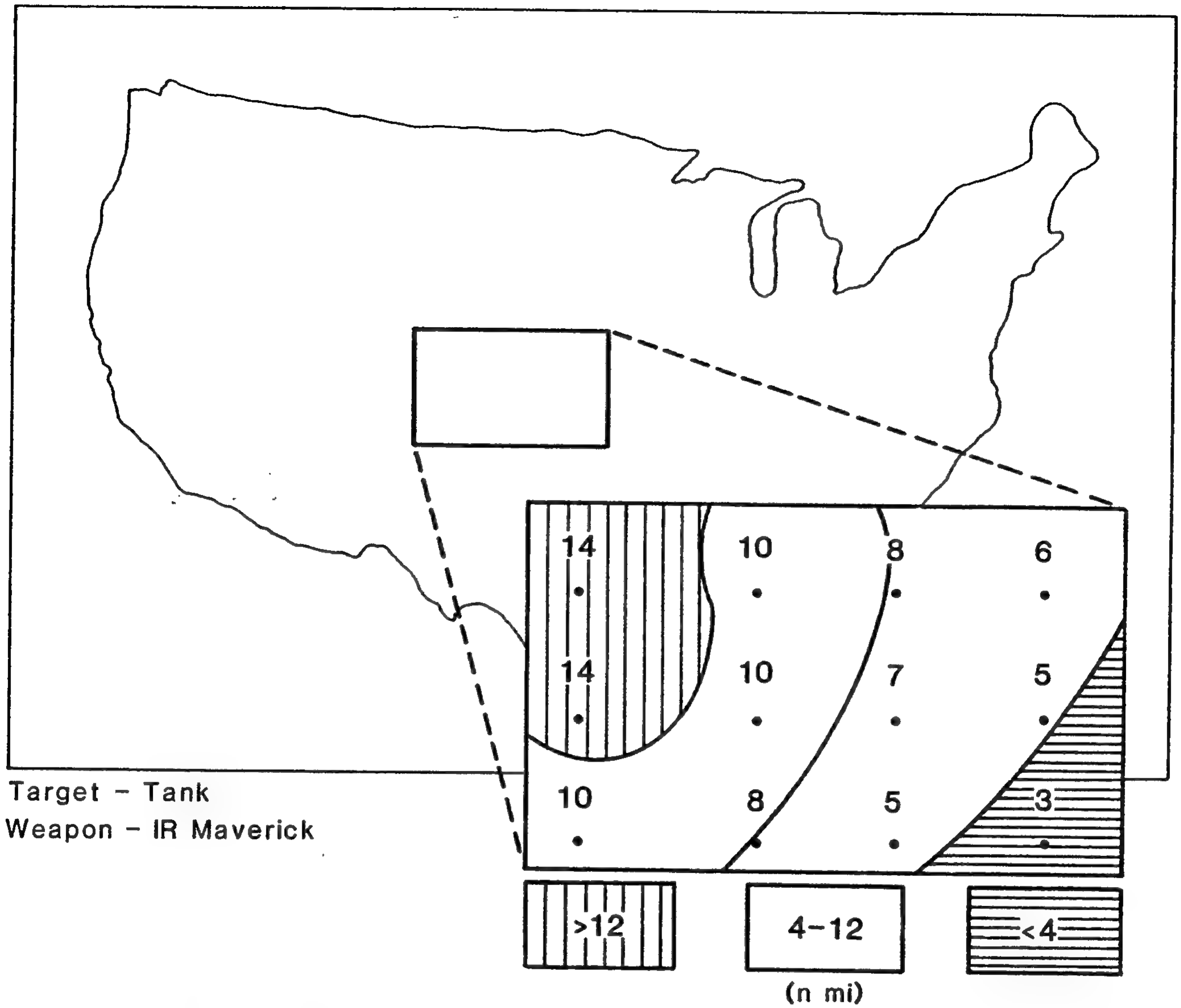
3. TACTICAL ENVIRONMENTAL PRODUCT SUITE FOR NAVAL AVIATION SUPPORT

While the Environmental Product Suite emphasized flight safety and efficiency, the Tactical Environmental Product Suite provides display information on environmental effects on weapons, sensors and platforms. This information must be provided to the strike mission planner in a manner which makes it as easy as possible to use. The goal is to assist the tactical decision maker and mission planner in optimum employment of weapon and sensor systems. In recent years this has become increasingly important due to the development and employment of environmentally sensitive "smart weapons" and the potential for third world/low intensity conflict (U.S. Navy, 1992a).

The products presented in this section emphasize tactical environmental decision making and may be viewed as individual products or ones that can be meshed or overlaid with strike warfare tools and capabilities (e.g., the Tactical Aircraft Mission Planning System).

3.1 EOTDA LOCK-ON RANGE



The Electro-Optical Tactical Decision Aid (EOTDA) provides the opportunity to predict the performance of EO sensors under various environmental conditions. Displays can be for individual points or geographically mapped for area coverage and can be for the present or forecast times. The lock-on values shown in this example are for an infrared system with a tank target. Decision makers might be uncomfortable about the short lock-on ranges in the southeast segment of the region and very comfortable with the longer ranges to the northwest if both target regions are defensively fortified.

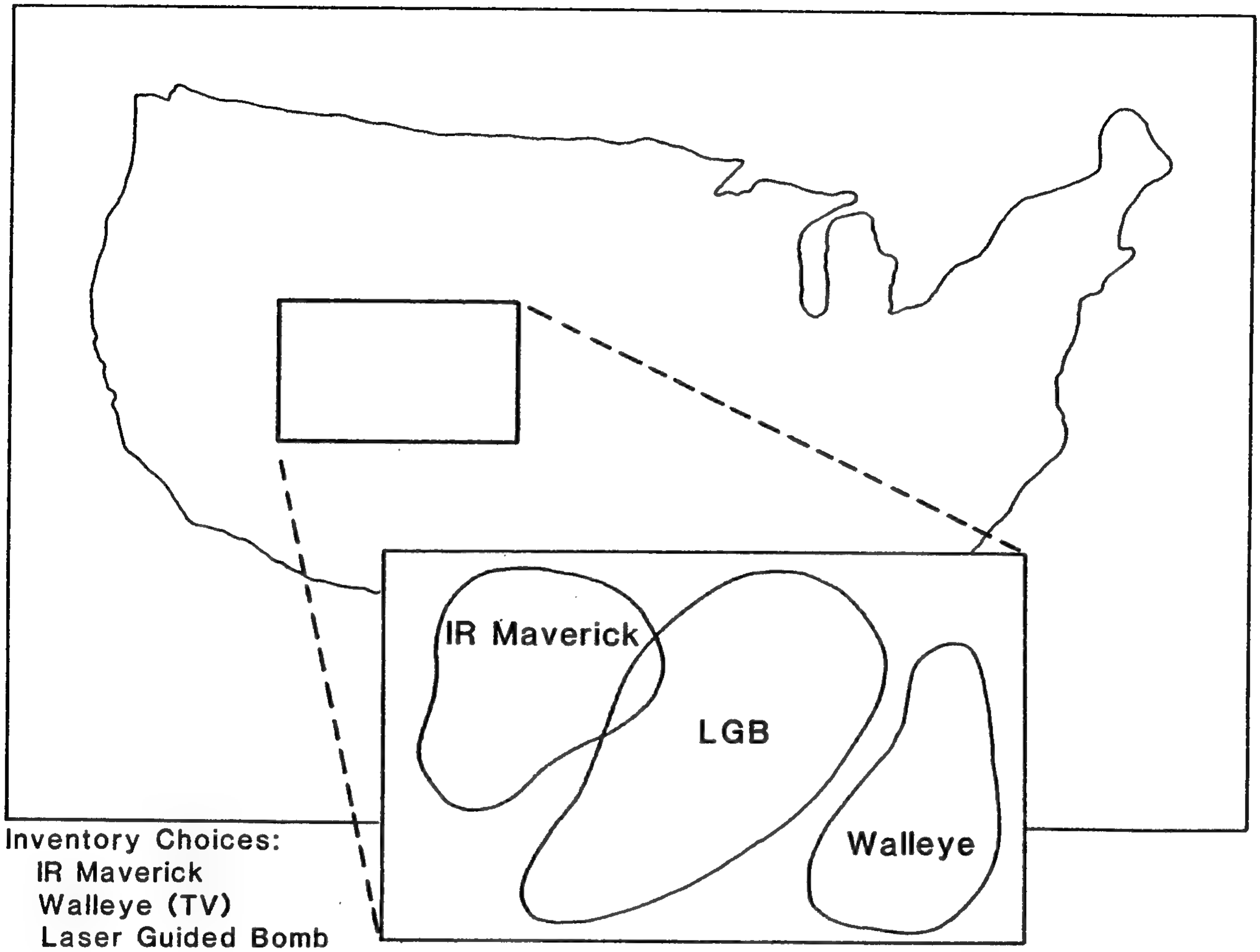
Requirements

The Tactical Aircraft Mission Planning System (TAMPS) has a functional requirement for the prediction of effective ranges for EO sensors (Lacey, 1992). EO parameters have been requested at a horizontal resolution of 10 nautical miles with a vertical resolution requirement at 1000 feet. Temporal resolution requirements range from hourly to 6 hourly out to 96 hours (PEO for Tactical Aircraft Programs, 1992 and 1993).

Technical Issues

The basis for the EO sensor graphical displays are the EOTDAs under development at the Naval Research Laboratory, Monterey. The product was derived from the Mark III EOTDA, which was originally developed at the USAF Phillips Laboratory (Higgins et al., 1990; and Hilton et al., 1990). The EOTDAs are computer programs that process information concerning the target, its background, the weapon system and the environment, and produce output in the form of predictions of system detection or lock-on ranges. The Naval Research Laboratory, Monterey is currently conducting an evaluation of the EOTDA sensor performance model for many of the Navy/Marine Corps sensors (Dreksler et al., 1994). This type of evaluation will ascertain a measure of confidence in the EOTDA algorithms or even document biases that exist. A further analysis needs to be done to determine the model output/environmental input error, particularly for more automated versions of the EOTDA. On-scene high resolution data collection, assimilation and analysis, as well as forecasting, should also be explored. Appendix A provides a description of the environmental parameters required to drive the EOTDA algorithms, with a technical discussion of each of these parameters.

3.2 OPTIMUM WEAPON SELECTION



The Optimum Weapon Selection display could assist decision makers in matching the best "smart weapon" choice within a region of interest. The differences arise due to the fact that the environment affects infrared, laser and visual sensors differently.

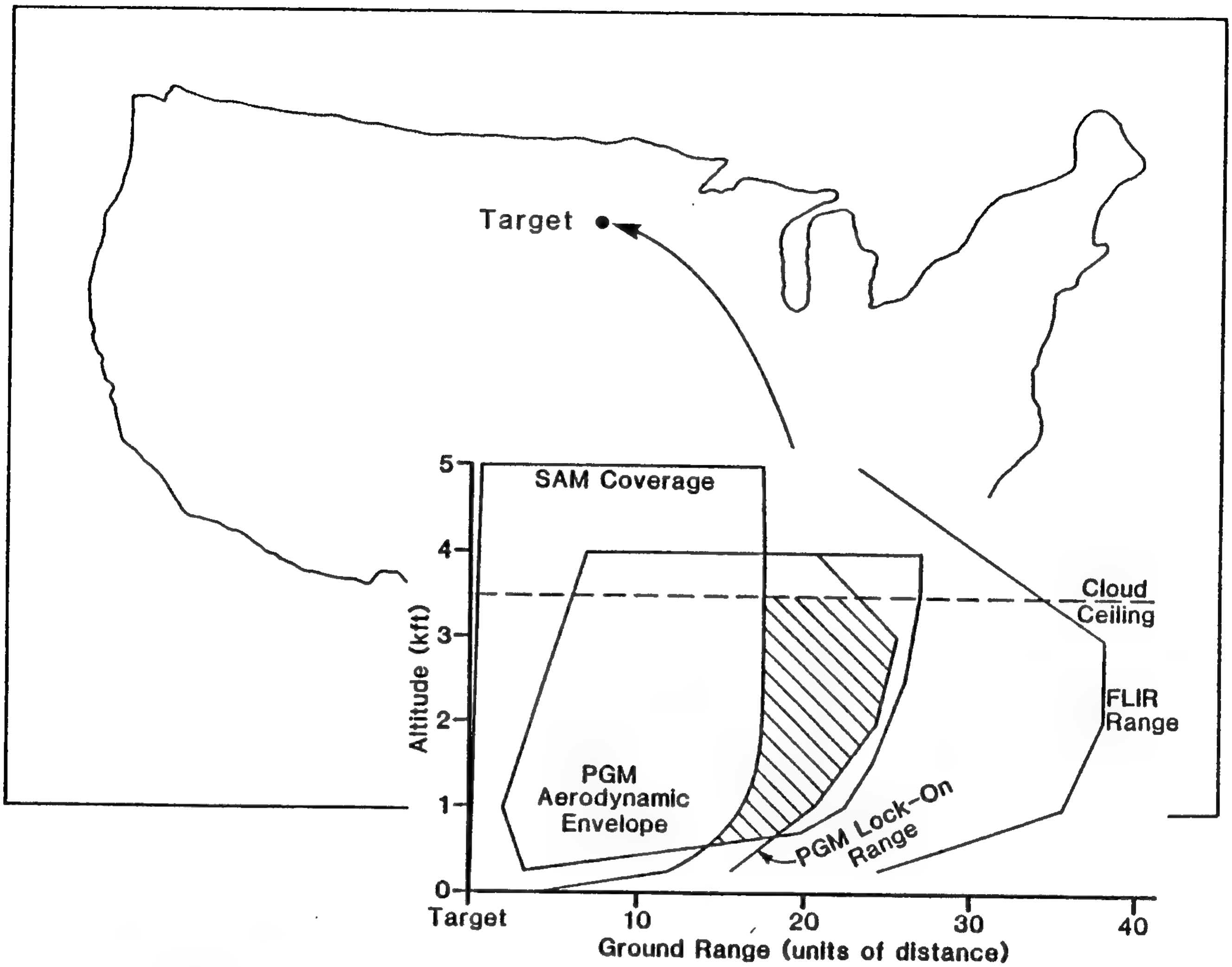
Requirements

While no explicit requirement exists for optimum weapon selection, TAMPS has a functional requirement for the prediction of effective ranges for EO sensors. The environmental community within the Navy has a requirement for the development of EO naval weapon system tactical decision aids - CINC MET 91-05 (CNMOC, 1993).

Technical Issues

EOTDA output, in combination with an understanding of environmental effects, could provide the basis for optimum weapon selection. Environmental effects for different types of "smart weapons" are reasonably well understood. For example, a high humidity atmospheric environment would certainly reduce infrared detection ranges and have less impact on visual sensors. A decision tree based on predefined selection criteria could assist in optimum weapon selection. The largest unknowns would arise in the environmental inputs that drive the environmental effects models. Evaluations are currently underway to establish sensor errors with follow-on studies expected to pursue the model output/environmental impact errors. As would be expected, the further out in the forecast period, the less confidence one would have in weapon selection decisions. On-scene high resolution data collection, assimilation and analysis, as well as forecasting, should also be explored. Refer to Appendix A for a description of the environmental parameters required to drive the EOTDA algorithms, with a technical discussion of these parameters.

ENVIRONMENTAL STRIKE PLANNING AID



The Environmental/Strike Planning Aid depicts the tactical environmental concerns of a pilot of an attack aircraft armed with precision guided munitions (PGMs) as he approaches the target. Knowledge of the existence and location of clouds can be used to conceal the aircraft from some threats during its mission. EOTDA output predicts when the target will first be detected on the aircraft's forward looking infrared (FLIR) display. Enemy surface-to-air missile (SAM) threat envelopes are of interest for obvious reasons. The aerodynamic envelope and predicted target acquisition and lock-on ranges for the PGMs will tell the pilot when he can expect to launch his weapon. The hatch-marked region of the display represents the optimum region for successful launch and egress from the target area.

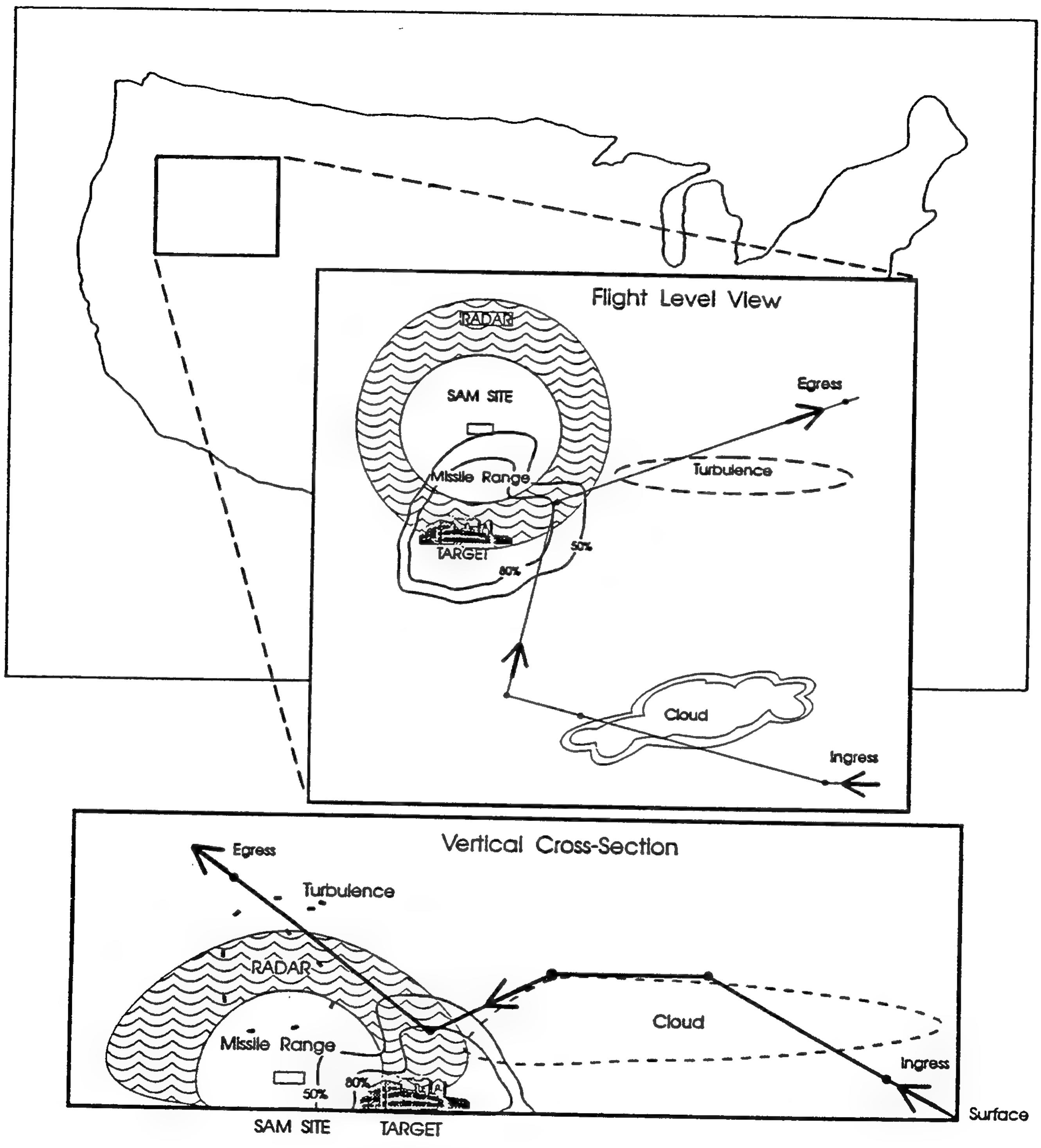
Requirements

TAMPS has a functional requirement for the prediction of effective ranges for EO sensors. The environmental community within the Navy has a requirement for the development of EO naval weapon system tactical decision aids - CINC MET 91-05 (CNMOC, 1993).

Technical Issues

Environmental Strike Planning Aids are useful in presenting a broader "big picture" of a number of tactical environmental concerns. When overlaid with electromagnetic (EM) coverage diagrams of defensive radar systems and terrain masking, the offensive and defensive picture is very attractive to decision makers. The technology demands are quite high because the horizontal and vertical atmospheric resolution requirements are very high. Confidence measures for the many environmental effects have yet to be established. EM range-dependent technology has been developed for over water (Hitney, 1992); over-land range-dependent propagation models are currently under development at the Navy Command and Control and Ocean Surveillance Center, RDT&E Division, San Diego. High resolution atmospheric models have been linked to range-dependent propagation codes and are just starting to be evaluated as to their refractivity forecasting skill (Cook et al., 1994; Burk et al., 1994; Love and Cook, 1994; and Thompson et al., 1994). On-scene high resolution data collection, assimilation and analysis, as well as forecasting, are just starting to be explored as inputs to EM applications and should also be explored for EO. New visualization and graphical computer techniques being developed would allow a three-dimensional display of the types of two-dimensional information described here. This gives mission planners a 3D fly-through to target perspective or observer perspective of the tactical scene. Refer to Appendix A for a description of the environmental parameters required to drive the EOTDA algorithms, with a technical discussion of these parameters.

3.4 ENROUTE STRIKE PLANNING AID



The Enroute Strike Planning Aid depicts the tactical environmental concerns of a pilot of an attack aircraft armed with precision guided munitions (PGMs) as he approaches a target and returns. This aid depicts weather hazards and tactical hazards at flight level for ingress, attack and egress. Knowledge of cloud locations can be used to conceal the aircraft from some threats during its mission. EOTDA output predicts when the target will first be detected on the aircraft's forward looking infrared (FLIR) display and the PGM lock-on range. This aid depicts different probabilities of PGM lock-on (currently not an EOTDA capability). Enemy surface-to-air (SAM) envelopes and enemy radar coverage are of interest for obvious reasons. Turbulence regions are areas that pilots try to avoid for flight safety.

Requirements

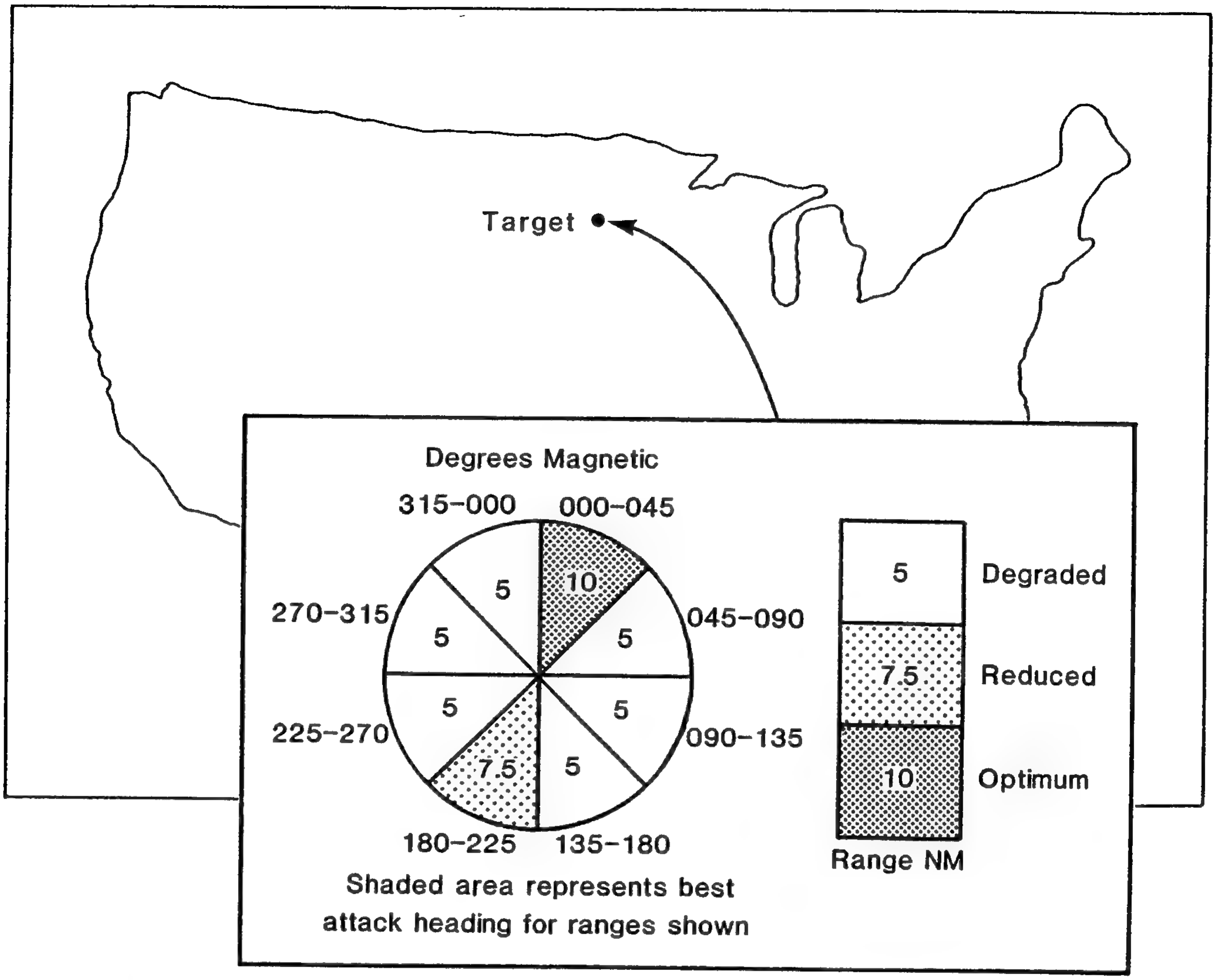
TAMPS has a functional requirement for the prediction of effective ranges for EO sensors. The environmental community within the Navy has a requirement for the development of EO naval weapon system tactical decision aids - CINC MET 91-05 (CNMOC, 1993).

Technical Issues

Enroute Strike Planning Aids are useful in presenting a broader "big picture" of a number of tactical environmental concerns. When coupled with terrain masking, the offensive and defensive picture is very attractive to decision makers. The technology demands are quite high because the horizontal and vertical atmospheric resolution requirements are very high. Confidence measures for the many environmental effects have yet to be established. EM range-dependent technology has been developed for over water (Hitney, 1992); over-land range-dependent propagation models are currently under development at the Navy Command and Control and Ocean Surveillance Center, RDT&E Division, San Diego. High resolution atmospheric models have been linked to range-dependent propagation codes and are just starting to be evaluated as to their refractivity forecasting skill (Cook et al., 1994; Burk et al., 1994; Love and Cook, 1994; and Thompson et al., 1994). On-scene high resolution data collection, assimilation and analysis, as well as forecasting, are just starting to be explored as inputs to EM applications and should also be explored for EO. New visualization and graphical computer techniques being developed would allow a three-dimensional display of the types of two-dimensional information described here. This gives mission planners a 3D fly-through to target perspective or observer perspective of the tactical scene. Currently the EOTDA only computes a single probability of detection (50%), data at only one sensor height, and a single target-sensor position. More EOTDA research, evaluation and feasibility studies are necessary to overcome these model limitations (Dreksler et al., 1994). Refer to Appendix A for a description of the environmental parameters required to drive the EOTDA algorithms, with a technical discussion of these parameters.

3.5

EOTDA EXECUTION AID



The EOTDA Execution Aid provides a graphical depiction of optimum attack headings to a particular target. The display can be set for different measures of degradation due to the environment.

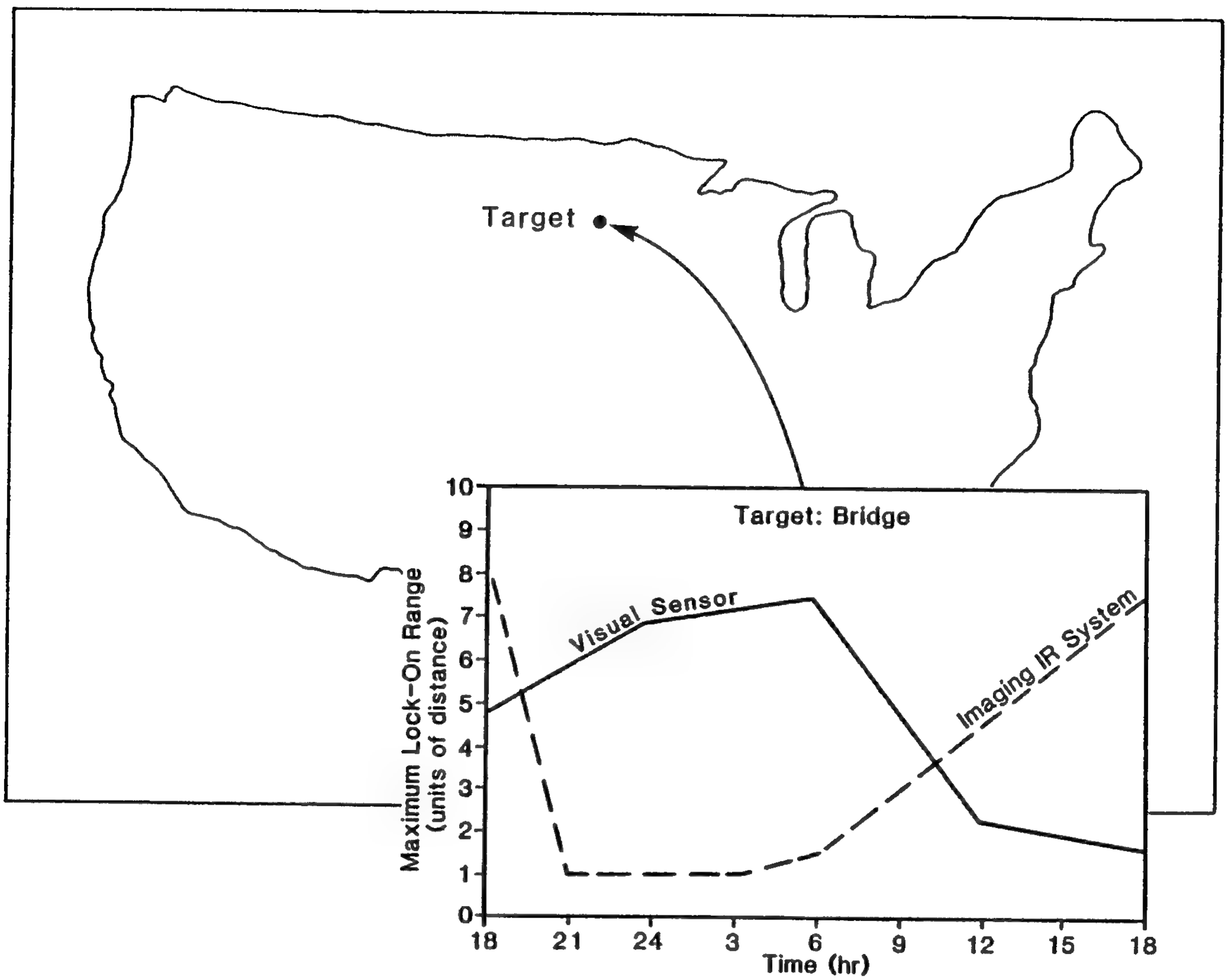
Requirements

TAMPS has a functional requirement for the prediction of effective ranges for EO sensors. The environmental community within the Navy has a requirement for the development of EO naval weapon system tactical decision aids - CINC MET 91-05 (CNMOC, 1993).

Technical Issues

The ability to detect a target is dependent on a number of variables including the target/background contrast, attenuation due to the atmosphere, and the type of sensor chosen. Detection ranges to a target can vary greatly as a function of approach direction due to the complexity of the above variables. The EOTDA Execution Aid could provide tactical decision makers a "quick look" view of optimum, reduced or degraded ranges for different approach corridors. This in combination with target choices and defensive measures could assist in targeting and retargeting. A variant of this product is currently produced as an eight-point range plot with the current version of the EOTDA. The range plots are very sensitive to target/background and solar considerations. On-scene high resolution data collection, assimilation and analysis, as well as forecasting, should be explored as an enhancement to the current environmental inputs. Confidence measures for the many environmental effects have to be established. New visualization and graphical computer techniques being developed would allow a three-dimensional display of the types of two-dimensional information described here. This would bring in the vertical aspects of optimum approach and attack and give mission planners a 3D fly-through to target perspective or observer perspective of the tactical scene. Refer to Appendix A for a description of the environmental parameters required to drive the EOTDA algorithms, with a technical discussion of these parameters.

3.6 EOTDA PLANNING AID



The EOTDA Planning Aid displays ranges as a function of time. This kind of product could be used to assist strike planners in selecting the best weapon for a particular time of day or the best time of day for a specific weapon system.

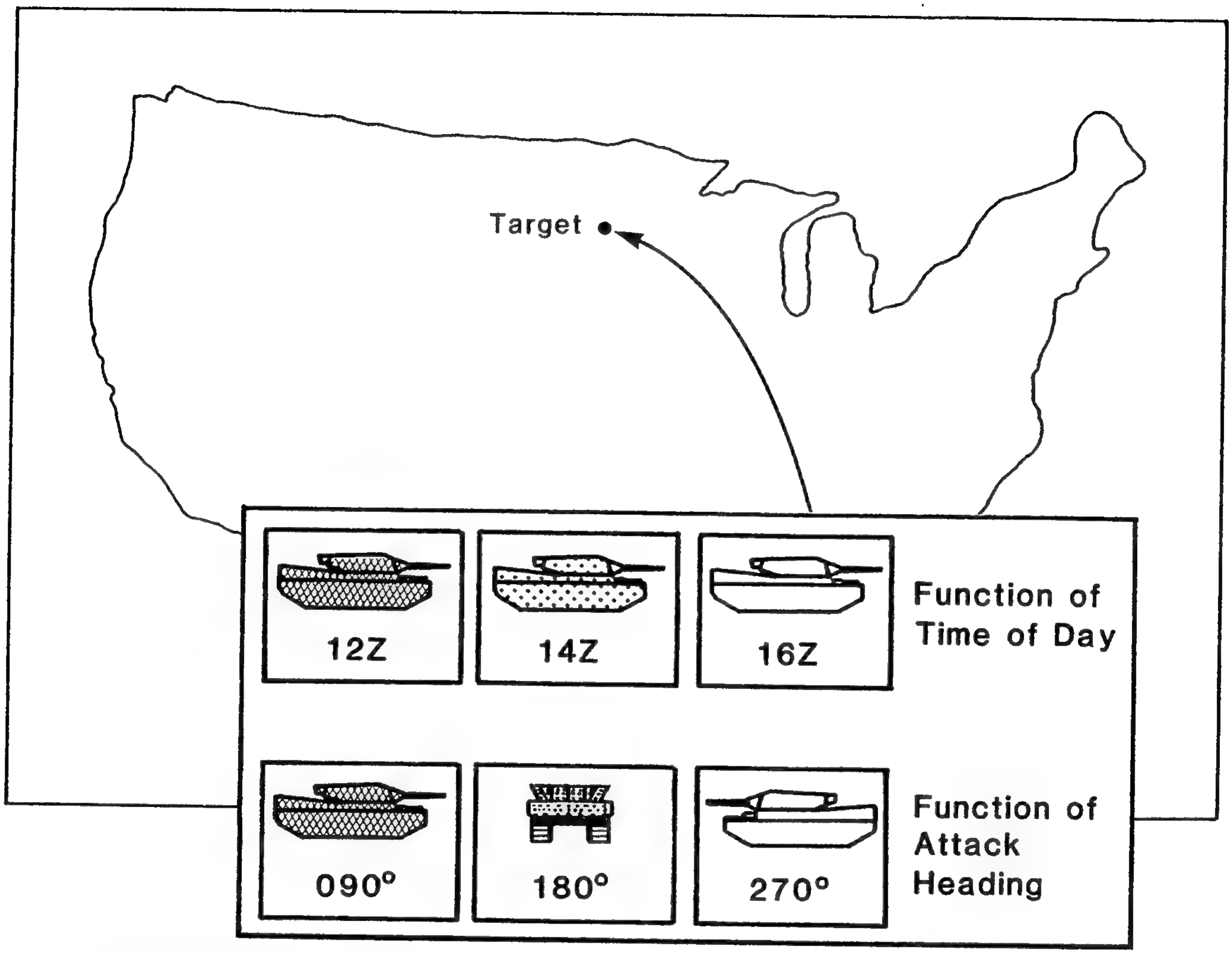
Requirements

TAMPS has a functional requirement for the prediction of effective ranges for EO sensors. The environmental community within the Navy has a requirement for the development of EO naval weapon system tactical decision aids - CINC MET 91-05 (CNMOC, 1993).

Technical Issues

Planning aids could be used to assist strike planners in the following: selecting the best weapon for a particular time of day; selecting the best time of day for a specific weapon system; displaying multiple sensors for different attack angles versus time of day; displaying multiple target/background scenarios versus time of day; and displaying multiple sensor heights versus time of day. The ability to detect a target is dependent on a number of variables including the target/background contrast, attenuation due to the atmosphere, and the sensor. Detection ranges to a target can vary greatly as a function of time of day due to diurnal environmental variations as well as mesoscale/synoptic scale variations. The technical challenge is more with the latter, since diurnal effects are certainly more predictable. The technology demands are quite high because the horizontal and vertical atmospheric resolution requirements are very high. In addition, the temporal requirements for model output as inputs to the EOTDA algorithms would be very demanding. On-scene high resolution data collection, assimilation and analysis, as well as forecasting, should also be explored as an enhancement to current environmental inputs. Confidence measures for the many environmental effects have to be established. Relative differences, if clearly established, could be used to assist strike planners until confidence is established in absolute terms. The time planning aids in combination with target choices and defensive measures could assist in targeting and retargeting. Refer to Appendix A for a description of the environmental parameters required to drive the EOTDA algorithms, with a technical discussion of these parameters.

3.7 TARGET VISUALIZATION



On-screen Target Visualization displays provide users the ability to simulate the target scene. This affords the opportunity to mission preview targets as a function of time of day, attack angle, etc.

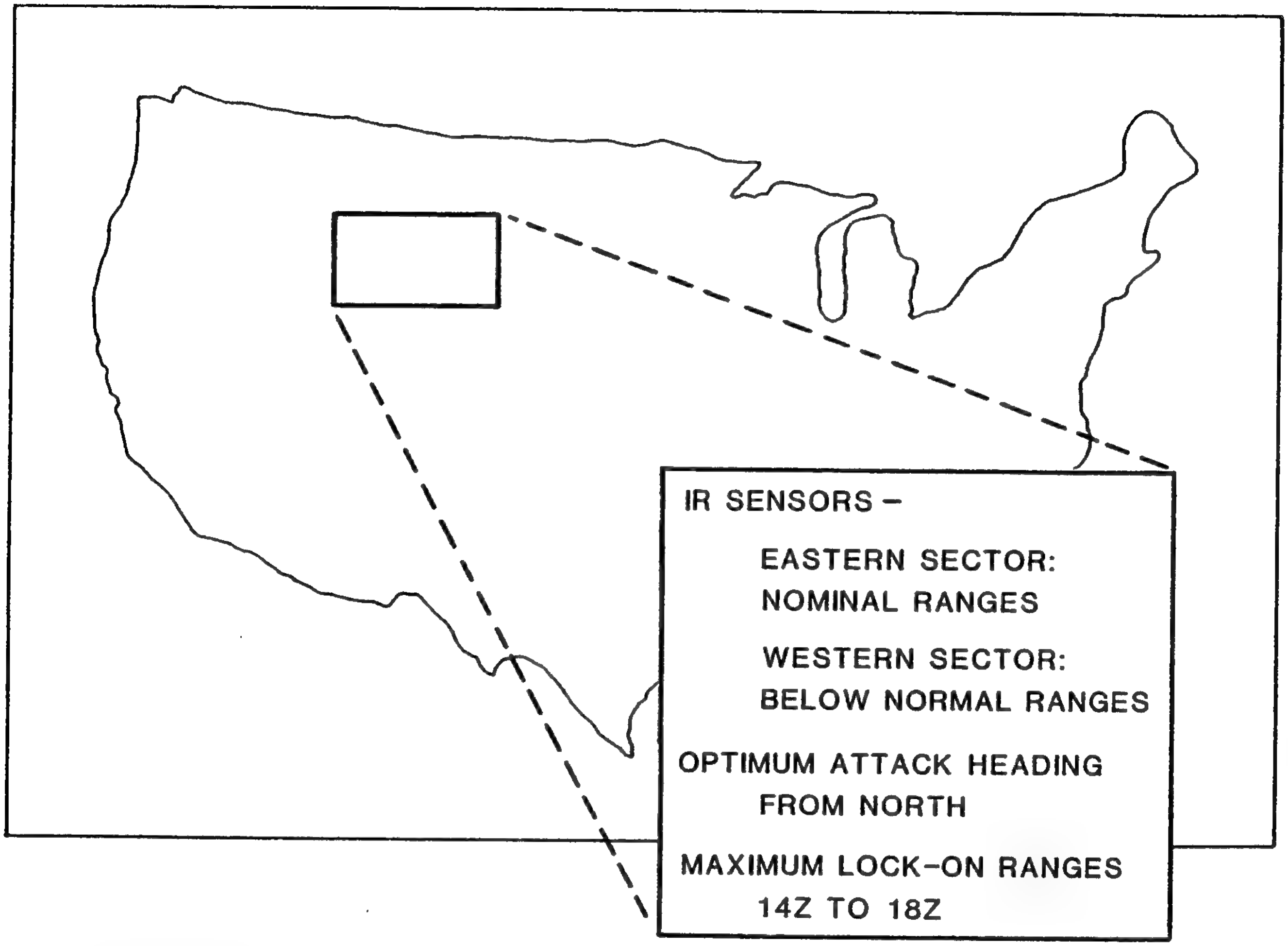
Requirements

TAMPS has a functional requirement for the prediction of effective ranges for EO sensors. The environmental community within the Navy has a requirement for the development of EO naval weapon system tactical decision aids - CINC MET 91-05 (CNMOC, 1993).

Technical Issues

Two of the seven key Science and Technology thrust areas for DoD deal with target visualization: precision strike, and simulation technology for training and readiness. Target visualization displays provide the user the opportunity to simulate the target scene for mission planning, preview or rehearsal in a simpler environment than more sophisticated mission rehearsal systems (e.g., TOPSCENE or POWERSCENE). Users can visually assess target recognition or detection as a function of a number of parameters including time of day, attack heading, etc. Some simple target visualization capabilities currently exist with the present PC and workstation versions of the EOTDA, Version 3.0 (Freni et al., 1993). These include the display of the target, background and sky temperature for the IR model of the EOTDA or the target, shadow and background radiance values for the TV model of the EOTDA. The values are displayed on a screen as shades of gray based on a user-defined scale. Targets can be displayed from any combination of azimuth and elevation angles. The incorporation of atmospheric effects and zooming is currently being explored in research efforts at the Naval Postgraduate School and at the Air Force's Phillips Laboratory.

3.8 PLAIN LANGUAGE ASSESSMENT



This display describes the output from the Electro-Optical Tactical Decision Aids in plain language format.

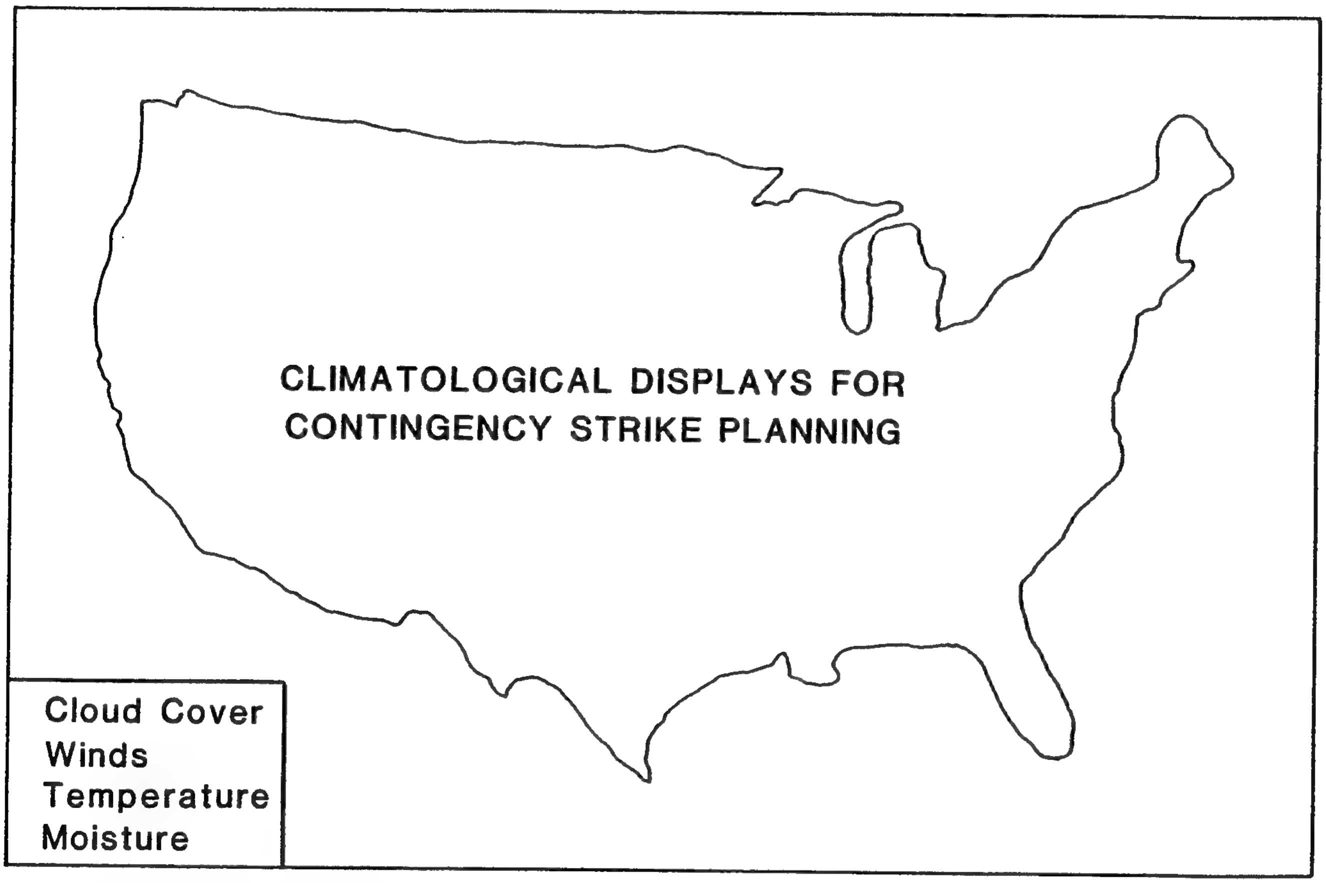
Requirements

TAMPS has a functional requirement for the prediction of effective ranges for EO sensors. The environmental community within the Navy has a requirement for the development of EO naval weapon system tactical decision aids - CINC MET 91-05 (CNMOC, 1993). In addition, one of the principal conclusions from the FLIR Performance Model User Survey (Cook and Larsen, 1986) was that users were interested in a plain language assessment of the tactical environmental output.

Technical Issues

A plain language synopsis of the EOTDA output could take the form of an index relative to some standard condition, or information relative to a particular target (e.g., optimum attack angle, time of day for maximum lock-on range, etc.). Worded tactical environmental insight requires an expert system approach to optimize phrases required for customers. The expert system would have to be developed via prescribed algorithms based on relative measures of mission success, experience and confidence in EOTDA output.

3.9 CLIMATOLOGICAL DISPLAYS



Climatological displays could be provided for individual environmental parameters such as cloud cover, temperature, moisture, wind, etc.

Requirements

TAMPS environmental requirements have been documented for climatological information for the following: weather patterns/fronts, hazardous conditions, icing, cloud coverage, winds, visibility, precipitation, obscurants, temperature, dew point, relative humidity, freezing levels, contrail levels, sea state, wave height, wave frequency, wave direction, ditch heading, currents, ocean fronts, ocean eddies, sea surface temperature, ocean temperature-depth relationship, EM/EO propagation parameters, ground cover, coastal ice edge and off-shore ice formations. Horizontal resolution requirements range from 10 to 60 nautical miles with vertical atmospheric resolutions ranging from 1000 feet to standard level information.

Technical Issues

Climatological information is primarily for contingency strike planning. Since weather forecasting skill is limited to approximately 6 days, any time frames of environmental interest longer than this have to resort to some form of climatology. A number of environmental parameters have well established climatologies (e.g., cloud, temperature, moisture, winds), but many of those outlined in the requirements do not exist and would need to be developed. Besides environmental climatologies tuned to specific parameters, "tactical environmental" climatologies could also be developed and used to provide weapon, sensor or platform impact (e.g., maximum lock-on ranges for IR Maverick for Target X in the month of June as function of time of day). The Naval Research Laboratory, Monterey is developing climatological databases for the Tactical Environmental Support System. The Fleet Numerical Meteorology and Oceanography Command Detachment, Asheville is the primary focal point for environmental climatological information.

4. SUMMARY

A two-pronged approach to environmental support of naval aviation has been presented. The first approach focused primarily on aviation safety, while the second focused on tactical mission planning. Both approaches were aimed at providing assistance to the ultimate customer, the naval aviator. The Environmental Product Suite and the Tactical Environmental Product Suite used in describing these approaches, and their accompanying discussions on requirements and technical issues, can be viewed from a number of perspectives. The operational environmental community can assess where we are at present to support these products, and what needs to be done for the future. The tactical mission planners need to assess the display aids as to functionality, and help to prioritize as to importance. The R&D community has to assess the quality of the present support with respect to the requirements and to look at the prioritization from the perspective of where we need to invest and what is achievable. For example, the Naval Research Laboratory, Monterey is presently exploring a number of technical aspects of this complex question and developing prototypes for demonstration purposes. The above is not a single snapshot, but is one that involves continuous interaction, particularly in a world of continuous technological changes. A logical follow-on effort would be a compilation of this interaction with a resultant matrix of where we are now and where should we be going in the short and long term. The framework presented in this report should provide a basis for the tactical and environmental communities to meet this challenge.

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APPENDIX A

ENVIRONMENTAL PARAMETER REQUIREMENTS FOR THE ELECTRO-OPTICAL TACTICAL DECISION AIDS (EOTDA)

A.1. Introduction

The EOTDAs*, developed in a tri-service effort, consist of software models that predict the performance of electro-optical weapon systems and night vision goggles (NVGs), based on environmental and tactical information. Results are displayed in alphanumeric and graphic formats. Environmental parameters are briefly discussed below. For further details see Freni et al., 1993. Tactical information includes time over target, target location and characteristics, sensor specifications and height, and background characteristics. Performance is expressed in terms of maximum detection and lock-on ranges or designator and receiver ranges.

The EOTDAs consist of three microcomputer-based programs supporting infrared (8-12 μm), visible (0.4-0.9 μm), and laser (1.06 μm) systems. Each program comprises three sub-models: an atmospheric transmission model, a target contrast model, and a sensor performance model. The visible includes low-light devices and direct view optics.

A.2 Environmental Parameters

The EOTDA uses a simple two-layer model of the atmosphere: a boundary layer and an upper layer. In the boundary layer, all relevant weather parameters are equal to the surface values. Above the boundary layer, aerosol, visibility, temperature and dew point are assumed constant. Using only two layers reduces both computation time and the amount of environmental input data required; but in many cases, the use of a two-layer model is insufficient to provide high degrees of accuracy. The EOTDA also assumes the atmosphere is horizontally homogeneous, a reasonable assumption unless frontal passage is imminent or the target is near the coast.

The EOTDA requires the following parameters:

Surface Temperature
Surface Dew Point
Wind Speed and Direction
Surface Aerosol Index
Surface Visibility
Present Weather (Rain, Snow or none)
Rain Rate
Boundary Layer Height

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* Currently available in personal computer (PC) format. EOTDAs are also on the Tactical Aircraft Mission Planning System (TAMPS) and the Tactical Environmental Support System (TESS) version 3b.

Cloud Height (base), Amount and Types for three layers
Upper-level (above boundary layer) Temperature
Upper-level Dew Point
Upper-level Aerosol Index
Upper-level Visibility

Additionally, the infrared (IR) EOTDA requires an additional 6 hours of antecedent surface and upper-layer environmental data (to stabilize the temperatures in the thermal contrast model) before the IR EOTDA can be run. The EOTDA is a specification model. In order to make a forecast, forecast weather data must be used. The EOTDA cannot forecast ranges beyond the time of the input parameters entered.

A.2.1. Surface Parameters

This section discusses the following surface parameters in greater detail:

Temperature
Dew Point
Wind Speed and Direction
Aerosol Index (including Fog)
Visibility
Present Weather (Rain, Snow or none)
Rain Rate
Low-level Cloud Height (base), Amount and Types

1. Temperature and Dew Point are used to calculate the radiative processes (including condensation and evaporation) that determine the thermal contrast between the target and the background. They also determine the molecular component of extinction, which is mainly due to absorption by water vapor.

2. Wind Speed and Direction are used to calculate radiative cooling and extinction. The direction is only important if rain is present or if the target is moving.

3. Aerosol Index refers to the dominant particulate present. The EOTDA contains 19 pre-defined aerosol indexes: Rural, Urban, Maritime, Tropospheric (usually upper-level), Desert, Navy Maritime (9 choices), Fog (2), and Camouflage Smokes (3) (Freni et al., 1993). The non-smoke indexes are based on LOWTRAN 7 aerosol profiles. Aerosol selection is important for the EOTDA extinction calculations: during the spring and summer months, the effect of the aerosol on EOTDA ranges greatly decreases.

   For the EOTDA, extinction for Rural, Urban, Maritime, and Tropospheric aerosol is dependent on visibility and relative humidity along the path. Extinction due to Desert aerosol is dependent on wind speed. The extinction coefficient for the Navy Maritime aerosol model depends on relative humidity, continentality (effect due to land) for the air mass, instantaneous wind speed, and average wind speed for the past 24 hours.

   There are two fog profiles, Advective Fog and Radiation Fog. The advective fog model characterizes very wet aerosols found in dense fogs, where visibility is less than 1000 m.

The radiative fog model describes aerosol properties in less dense fogs where visibilities are 1000 m or greater. Fog has a significant effect on transmissivity.

4. Visibility is a major factor in extinction due to fog, camouflaged smokes and snow. Extinction generally increases with decreasing visibility.

5. Rain (snow) and Rain Rate affect the models in the IR EOTDA governing insolation, transmittance, and target and background temperatures. When rain is selected, overcast clouds at all levels are automatically entered into the insolation model. The range is very sensitive to rain, but rain rate as defined by the IR EOTDA, has little effect. Reduced transmissivity and thus reduced ranges results from heavier rain; however, evaporation is much more significant in reducing ranges. Evaporation reduces the thermal contrast between the target and background, and is not effected by rate, once the surfaces are wet. Rainfall continues to affect the scene for at least 12 hours after the end of significant rain (Keegan, 1990). In the TV and Laser EOTDA, reduced transmissivity and thus reduced ranges result from larger rain rates.

6. Low Cloud Parameters include cloud height (of cloud base), cloud amount in eighths, and cloud type. Clouds can be in the boundary layer or above the boundary layer. Clouds only affect the temperature of the target and the background. Clouds don't affect the transmissivity between the target and the sensor (EOTDA assumes a cloud free line of sight) unless there is an undercast between the sensor and the target. In the latter case, no EOTDA prediction is made. The only significant effect of clouds on TV EOTDA ranges is whether the target is in shadow or direct light.

A.2.2 Upper Level Parameters

This section discusses the following upper-level parameters in greater detail:

Boundary Layer Height
Temperature
Dew Point
Aerosol Index
Visibility
Cloud Height (base), Amount and Types for three layers

1. Boundary Layer Height (inversion height) divides the atmosphere into two layers, a boundary layer and an upper layer (defined from boundary layer to sensor height). In the EOTDA, all relevant weather parameters are equal to the surface values below the boundary layer. Above the boundary layer, all relevant weather parameters are constant. Boundary layer height is important when the sensor is above the boundary layer.

2. Upper-Level Temperature, Dew Point, Aerosol Index, and Visibility are used to define an extinction coefficient. These parameters were found to have little impact on EOTDA ranges. Only transmittance is affected by the upper layer, and its overall value is normally dominated by conditions in the lower layer.

3. Cloud Parameters include cloud height (of cloud base), cloud amount in eighths, and cloud

type. Clouds only affect the temperature of the target and the background. Clouds don't affect the transmissivity between the target and the sensor (EOTDA assumes a cloud free line of sight) unless there is an undercast between the sensor and the target. In the latter case, no EOTDA prediction is made. The combined amount of middle and low clouds is generally the most important cloud parameter. The EOTDA is not sensitive to high clouds when low clouds are present, nor is it sensitive to the altitude of the clouds in the two lowest layers (assuming the clouds are not between the sensor and the target). The only significant effect of clouds on TV EOTDA ranges is whether the target is in shadow or direct light.

A.3. Technical Issues

Benefit can be derived from upgrading all three sub-models in the EOTDA. However, from an environmental point of view, the atmospheric transmission model can provide the most improvement for the smallest investment. An atmospheric model that allows for multiple non-homogenous layers could greatly increase the accuracy of the EOTDA model output. The EOTDA already requires a great deal of environmental input data. This increased resolution model would further increase the amount of weather inputs required and increase the computational requirement. A study to determine optimum tradeoffs between increasing resolution versus run time and data entry is recommended.

A necessary step before fielding a high resolution transmissivity model is to automate the data entry for the EOTDA using a predefined weather database or numerical model output data. However, existing weather databases don't provide all the necessary environmental parameters at the accuracy needed by the EOTDA, especially for forecasts of aerosols, visibilities, present weather and dew point. Therefore, a man-in-the-loop is required to at least check the accuracy of the parameters and to fill in those parameters that can't be forecast.

The EOTDA is sensitive to every environmental parameter listed above in A.2, such that a small change in the value of any input parameter may have a significant effect on the EOTDA model output. Conversely, in some cases, range can be insensitive to large changes in input. So it is important to understand the model better, and more sensitivity studies and field evaluations are necessary to quantify the EOTDA model properties.

Currently, forecasted values and observations in data sparse regions (i.e., at the target) of visibility, present weather, aerosols and dew point do not appear to be of the accuracy required by the EOTDA. More research is needed to determine the required accuracies of enroute and target weather inputs and to determine how to achieve those accuracies.